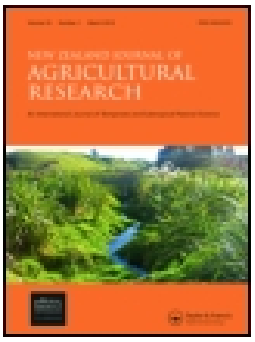

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First measurements of methane emitted by grazing cattle of the Argentinean beef system

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Abstract We report the first measurements of methane emitted by cattle of the Argentinean beef system, one of the largest in the world. Special care was taken to keep the animals under production conditions typical of the Pampa, the main livestock region of the country. Therefore, we applied the SF_6 tracer technique to 20 young Aberdeen Angus steers randomly chosen in a commercial farm, in which paddocks they were left to graze. The liveweight change of the animals, the herbage allowance and quality were followed during the research. The magnitudes varied significantly throughout the experiment (which included two separate periods of time, the first during December 2005 and the second in February–March 2006) and from paddock to paddock. In spite of these differences, the average daily methane emissions per head rarely depart from 170 g/day. However, larger variations were observed in the methane yield and, specially, in the methane emitted per weight gained. The work was also useful to analyse some technical features of importance in making the technique suitable for growing steers under the extensive condition prevailing in the Argentinean beef system.

Keywords grazing; beef cattle; methane emission; SF_6 tracer technique

INTRODUCTION

About half of Argentinean anthropogenic emissions of Greenhouse Gases (GHG) comes from farming activities. According to the Second National Argentine Communication to the IPCC (Argentine Government 2007), and to the EDGAR database (EDGAR 3.2 1995), the CH_4 and N_2O emitted as a consequence of livestock and agriculture slightly exceed (in C equivalents) the total resulting from fossil combustible burning. Especially important is methane emitted by enteric fermentation in cattle (about 50 000 000 head, devoted to beef production except a small fraction of dairy cows), which contributes to c. 25% of total emission budget. Other ruminant species are of less relevance.

Although the Argentinean GHG emissions are less than 1% of the world's total, the per capita contribution is about twice the global average. In particular, according to the EDGAR database, Argentina occupies the sixth place in total methane emission from domestic ruminants, after India, Brazil, China, Russia and the United States, and the corresponding per capita value is also one of the highest in the world. Therefore, studies on methane emissions from cattle are of interest to the country. In particular, we describe here the first application of the SF_6 tracer technique (Johnson et al. 1994) to measure methane emission in Argentina.

The primary objective was to measure average emissions under conditions typical of the Argentinean commercial beef cattle system, characterised by free grazing with a tendency toward zonal grazing in large paddocks. Therefore, the technique was applied to a homogeneous group of Angus steers freely grazing without nutrition supplement in the paddocks of a commercial farm

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(Estancia La Bernarda) located in the main Argentinean livestock region. The Aberdeen Angus breed is the dominant breed in this system, and the number of Angus steers is estimated to be around 4 500 000 (c. 9% of the country cattle total). We allowed the herbage allowance and quality to change in space and in time as it is normal during a commercial growing process. However, we measured its parameters in collected samples.

MATERIALS AND METHODS

Site, animals and general organisation of the experiments

The main part of the Argentinean beef cattle system is allocated in the Pampa, a c. 600 000 km^2 plain located between 30–39°S and 57–68°W. The Estancia La Bernarda, the farm where field work was carried out, is in the south-east part of the region at 37°12.58′S and 58°59.88′W, about 20 km from our University Campus.

The Pampa is characterised by a temperate climate with marked seasonal changes and relatively cold nights even in summer. During the experimental period (December–March) the daily average temperatures at the farm were about 20°C, and the early morning minima were around 10°C. Across the region humidity decreases westward and the same occurs with rainfall, that in the most of the Pampa is evenly distributed over the year. In particular, at the experiment site, rainfall averaged c. 70 mm/month (however, from the beginning of December 2005 to 21 February 2006, the rainfall was very scarce).

Livestock, especially beef cattle, prevail on the poorly drained south-east and central part of the Pampa, where typical average cattle stocking rates are around 1–1.3 head/ha, while in the remaining part, mainly devoted to cropping, the stocking rates of the cattle population falls below 0.5 head/ha. In the livestock regions the indigenous grass coverage has been largely substituted by a mixture of *Festuca arundinacea*, *Trifolium repens*, *Lolium multiflorum*, and other herbage species. The farm selected for the experiments is located at the edge of a well drained agricultural region near a north-west–south-east oriented hill range (the Tandilia System) and the herbage covering its paddocks is typical of the livestock region.

The animals were 20 Angus steers randomly chosen at the end of November 2005 from a head of about 2000 cattle grazing on the Estancia La Bernarda. At that time they were 14–16 months old and they weighed on average 265 kg, with a liveweight (LW) distribution width of the order of 5%. Hence, they constituted a homogeneous group representative of Pampean beef cattle system. As energy requirements for the category are limited to maintenance, activity and growth, calculation of the gross energy intake requirement (GE) and, hence, the determination of the methane yield (Y_m), is reasonably reliable.

The SF$_6$ permeation tubes were introduced in the rumens of the steers on 1 December (day 0 of the experiments) and the sample collection began on 6 December 2005 (day 5). In the first experiment (Experiment 1) the animals were divided in two paddocks, one of 2.11 ha (Experiment 1a) with herbage naturally growing without fertilisation for many years (RL = range land), and the second of 3.3 ha (Experiment 1b) with recently sown and fertilised herbage (SP = sown pasture). For reasons described below, almost all samples came from the 2 last weeks of the experiment, which ended on 22 December (day 21). To allow comparison in behaviour and growth, the 10 loaded steers in the first paddock were accompanied by five more not loaded and by two mature females weighing about 630 kg. In the second, the 10 loaded steers were accompanied by five not loaded and three mature females weighing 636, 582 and 550 kg.

The sampler sets were installed on the steers between 6 a.m. and 8 a.m. for 3 consecutive days each week (Tuesday, Wednesday and Thursday), beginning on Tuesday 6 (day 5). According to the initial programme, we planned to remove and replace the canister each 24 h leaving the animals without canisters from Friday morning to the next Thursday. Weighing was planned every Friday morning. Experiment 1 was extended for 3 weeks so that the last samples were collected and the last weighing made on Tuesday 22. This strategy required two suites of canisters (the one removed became free once the collected samples were transferred to 0.5 litre cylindrical vessels prior to their transportation to the analysis laboratory). However, from the first day many canisters were lost, so that it was only after a new two-vessel set described below was introduced, that the sample collections proceeded normally.

Thanks to the long useful lifetime of the SF$_6$ permeation tubes (c. 2 years), a second experiment (Experiment 2) was carried out on the same animals from 20 February (day 81) to 9 March 2006 (day 98) to confirm the results and also try some technical modifications. In this case all the animals were allocated to a single large paddock (12 ha) with herbage as SP, but only half of them were fitted with sampler sets. Experiment 2 was considerably affected by bad weather conditions, therefore, most of the samples were collected between 28 February and 9 March.

In Experiment 2 samples were collected in single cylindrical 0.5 litre PVC vessels equipped with the air inflow regulators described above. The entire sets (vessels plus regulators) were replaced daily, because the inflow air regulators need to be frequently monitored. In spite of the reduction of collection volume, the 24 h collection time could be maintained (i.e., air inflow rate was $\approx 3 \times 10^{-4}$ ml/s for a pressure difference of 1 bar). However, because of the low number of available sample sets, we decided to install them on no more than 10–12 different animals during 6 consecutive days. Early in the morning (6 a.m.) of 20 February (day 81) the steers were weighed, 12 of them were equipped with sampler sets and, together with two mature females of about 580 kg, they were allocated to a single 12 ha paddock with sown pasture (SP).

In this experiment the animals were supposed to be weighed every time the sampler sets were replaced (every morning). However, during the second day of the experiment, day 82 (21 February), the weather became so bad that access to the paddock was possible only on 27 February. Not only did we lose the samples, but also many of the sampler sets installed on 21 February were severely damaged. For this reason the experiment was effectively started on day 88 (27 February). Other periods of bad weather caused further shorter interruptions so that we did not have samples corresponding to 4, 5, and 7 March.

To have baselines for the CH_4 and SF_6 mixing ratios, we collected "pure" air samples near the paddocks and during the experiments, using sets identical to those used on the animals.

Permeation tubes

Since the above quoted pioneer work of Johnson et al. (1994), the SF_6 tracer technique has been extensively described and used, especially in New Zealand by K. Lassey, M. Ulyatt and their coworkers. A detailed description of the SF_6 permeation tubes (PT) and their properties was published by Lassey et al. (2001). In fact, we used PT provided by the National Institute of Water and Atmosphere (NIWA, NZ) and designed for cows, with permeation rates around 4 mg SF_6/day. After a brief pre-calibration in New Zealand, an accurate gravimetric calibration at 39°C was carried out for 5 weeks in our university. The PTs were weighed every 3 days and the values obtained were fitted by mass versus time linear regressions. The correlation factors for the regressions were at least 0.9996 for all the 20 PTs used in the experiments. Ten of the remaining PTs were used in a parallel laboratory experiment designed to determine the dependence of the SF_6 permeation rate on the temperature (T) within the range 35–43°C. The results show that the permeation rate increases about 3% per °K over this interval, a relative increment which is of the same order of the relative variation of the SF_6 vapour pressure as given in fluor and derivates (Solvay 2006). Note, however, that the gas in the PT is near to the critical point for SF_6 (T = 45.58°C, pressure = 37.59 bars, density = 0.74 kg/litre).

Collection of gas samples

The gas samples were collected in initially void PVC vessels into which air inflow was regulated to accumulate a pressure of c. 0.5 bar after 24 h.

The sampler sets for Experiment 1 were prepared following an illustrative report by Johnson & Westberg (1994). We built a number of sealed PVC U-shaped 1.5 litre canisters to be placed behind the head of the animals. We used segments of thick PVC tube (ID 42 mm, OD diameter 50 mm) joined at right angles, curved at high temperature and sealed. A valve was allocated on each canister to allow evacuation before use and, later, collection of the air sample through the inflow regulators that will be described below. All canister-valve sets were accurately controlled by inserting them on a small volume reticule where pressure was measured both by a Pirani gauge (0.01–30 mb) and a piezoelectric differential manometer (0–1200 mb with 1 mb precision). We accepted only sets where the air input with the valve closed was around 1 mb/day or less. However, we observed that such low rates were achieved only after a systematic initial accumulation of some mb (typically 5–8) occurring in a few hours. This initial accumulation did not disappear after a degassing treatment which consisted of keeping the void vessels at about 50°C for some days. It is related to the use of PVC, because it did not occur in stainless steel or aluminum vessels, which were tried in the laboratory although not used in the experiments.

Following recommendations of Johnson & Westberg (1994), in the first experiment we used input regulators made of 0.1 mm ID stainless steel (SS) capillary tubes 1 m long that give an air inflow c. 10^{-3} ml/s for a pressure difference of 1 bar between extremities.

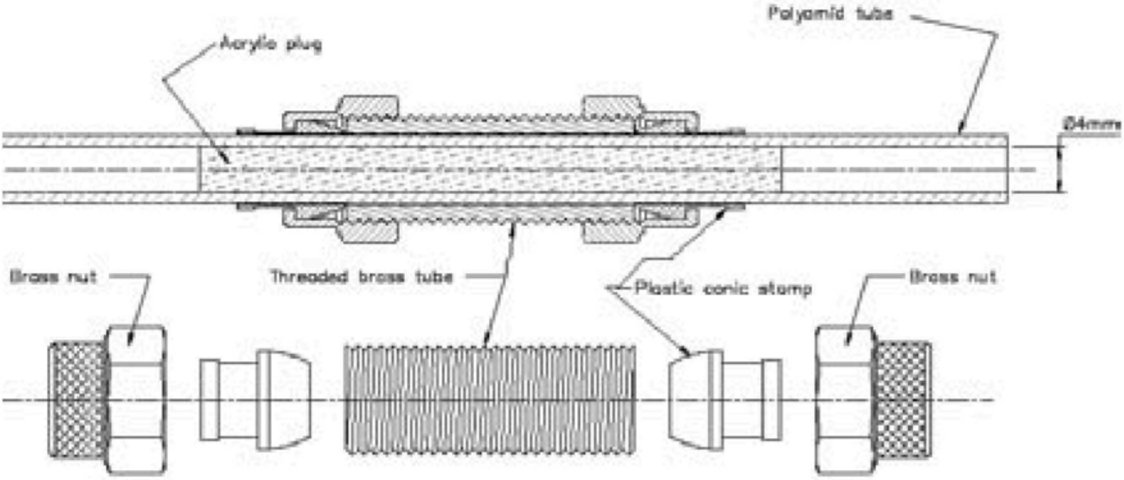


Fig. 1 Schematic representation of the inflow regulators prepared for Experiment 2. The air flows along micro-channels between the acrylic plug and the polyamid tube.

As the samples were analysed in a remote laboratory (see below), for easy transportation and conservation we partially transferred the collected gas to 0.5 litre cylindrical PVC vessels. Vacuum trials showed that these cylindrical vessels behave like the canisters. However, probably thanks to their simple configuration, their gas tightness was somewhat better. As a general rule, the time interval between collection and analysis was 10–15 days.

Soon after the beginning of Experiment 1 and partially as a consequence of the halters we used, it became clear that the sets were too rigid and fragile for our working conditions. Many canisters broke at the middle, probably due to contact between animals, and some capillary tubes were violently separated from the union joint which connected them to valves. As a result, very few air samples were collected during the first days. In order to overcome these difficulties each canister was replaced by two of the cylindrical vessels prepared for the sample transportation. They were placed into pockets attached to the halter on either side of the neck and connected to a single capillary tube by 4 mm ID polyamid tubes c. 25 cm long joined by a T union. These sets worked very well, and were used in the final part of the experiment. However, as the total volume was 1.0 litre instead of 1.5 litre, a proper regulation of the air input would require SS capillary tubes 1.5 m long, not disposable and expensive. Therefore, different sampler sets were prepared for Experiment 2, based on a single 0.5 litre cylindrical vessel and the low cost air inflow regulator schematically represented in Fig. 1.

A 4 mm ID polyamid tube is pressed from outside against an inner acrylic plug inserted near one of its extremities. This is made by two plastic conic stamps pressed by nuts. These inexpensive devices may be easily adjusted to reduce the air inflow rate to very low values. However, their impedances are affected by long-term changes, probably due both to slow mechanically and/or thermally induced plastic deformations. In fact, less than one half of the built acrylic plug regulators could be used for the experiment (the criteria was that impedance changes should not exceed 20% over 3 days) and we had to submit all of them to cumbersome pre- and post-usage testing.

Sampling of herbage

In both the RL and SP paddocks pasture was a mixture of different species. In RL the main species were *Festuca arundinacea*, *Trifolium repens* and *Lolium multiflorum*. In addition, in the SP we had *Trifolium pretense* and *Lotus corniculatus*.

During Experiment 1 we cut weekly six random samples at ground level in each paddock within a 1250 cm^2 frame. In each sample we first determined the fresh weight of the four basic groups of components: legumes, grasses, shrubs and dead matter. Then they were dried together at 60°C till reaching a constant weight. This gave the total dry matter (DM) weight of the six samples (7500 cm^2), and allowed an estimation of the DM contribution at each group component, which was assumed proportional to the respective fresh weight.

When ground and mixed, the DM was analysed to determine its chemical composition and digestibility. Crude protein (CP) was measured by Kjeldhal technique applied to micro samples, neutral detergent fibre (NDF) and acid detergent fibre (ADF) by Van Soest technique (Goering & Van Soest 1970), dry matter digestibility (*DE*) by Tilley and Terry technique (Tilley & Terry 1963) and the non-structural carbohydrates (NSC) by the Anthrone technique (Yemm & Willis 1954). The metabolisable energy (ME) (MJ per kg of DM) was also calculated.

Measurements of methane emission and calculation of methane yield

The mixing ratios of CH_4 and SF_6 in the collected gas samples were determined by chromatography in a specialised laboratory (INFQC Universidad de Córdoba, CONICET, Córdoba, Argentina). The samples were injected at once in two different setups. For CH_4 we used a 3 ml loop, a HP-PLOT Q column and a FID detector. For SF_6 a 10 ml loop, a HP-MOLSIV column and a ECD detector. Each sample was analysed at least twice and the average values were used to calculate the daily methane emission E_m from the quotient of the mixing ratios of the two gases after subtracting the baseline values.

For methane yield Y_m, i.e, the ratio between the energy content of E_m and the *GE*, the energy requirement model recommended by the IPCC (1996) was need to calculate *GE*. For steers this model relies on the knowledge of the animals liveweight (LW), liveweight changes (LWG) and average *DE*. As said before, *DE* was obtained by measuring *in vitro* the average digestibility of the dry matter sampled in the paddocks. Possible differences with respect to the average digestibility of the pasture actually ingested by the animals' will be discussed later.

RESULTS

Herbage composition

Table 1 shows the change in DM (kg/ha) for each period in Experiment 1 in both paddocks. Even though the amount of DM during the experiment did not change very much, the composition varied strongly, with legumes, grass and shrubs declining and dead matter increasing.

The chemical composition and the digestibility are shown in Table 2.

Table 1 Groups of components (in percentages) of the dry matter (DM) in the two paddocks of Experiment 1. Total DM in kg/ha. RL, Range land; SP, sown pasture.

	Legumes (%)		Grass (%)		Shrubs (%)		Dead matter (%)		Total DM (kg/ha)	
Day	RL	SP	RL	SP	RL	SP	RL	SP	RL	SP
4	4.82	9.95	56.11	64.02	0.38	6.10	38.68	19.93	2094	3377
11	0.32	6.15	62.21	70.05	7.19	1.03	30.28	22.78	1265	3512
18	0.30	9.03	33.48	44.69	1.01	5.09	65.20	41.19	2661	1828
25	0.30	5.27	37.59	18.04	0.00	8.87	62.10	67.82	1987	2750

Table 2 Quality of the herbage allowance for the two experiments. Neutral detergent fibre (NDF), acid detergent fibre (ADF), crude protein (CP), dry matter digestibility (DE), metabolisable energy (ME) MJ per kg of dry matter (DM) and non-structural carbohydrates (NSC). RL, Range land; SP, sown pasture.

		NDF		ADF		CP		DE		ME		NSC	
Experiment	Day	RL	SP	RL	SP	RL	SP	RL	SP	RL	SP	RL	SP
1	4	58.6	56.4	36.7	34.5	9.3	7.6	60.4	63.4	9.2	9.6	7.0	12.0
	11	57.8	57.8	34.0	33.2	8.4	6.5	64.6	69.8	9.6	10.5	8.1	13.9
	18	61.1	58.0	37.5	35.2	6.7	7.0	46.7	64.4	7.1	9.6	6.4	13.1
	25	67.2	67.6	37.9	39.0	7.6	5.7	51.7	60.6	8.0	9.2	5.9	9.7
Average		61.2	59.9	36.5	35.5	8.0	6.7	55.9	64.5	8.4	9.6	6.8	12.2
2	81		52.5		32.4		10.5		60.5		9.2		5.6
	104		50.9		31.3		11.9		65.5		10.0		
Average			51.7		31.8		11.2		63.0		9.6		5.6

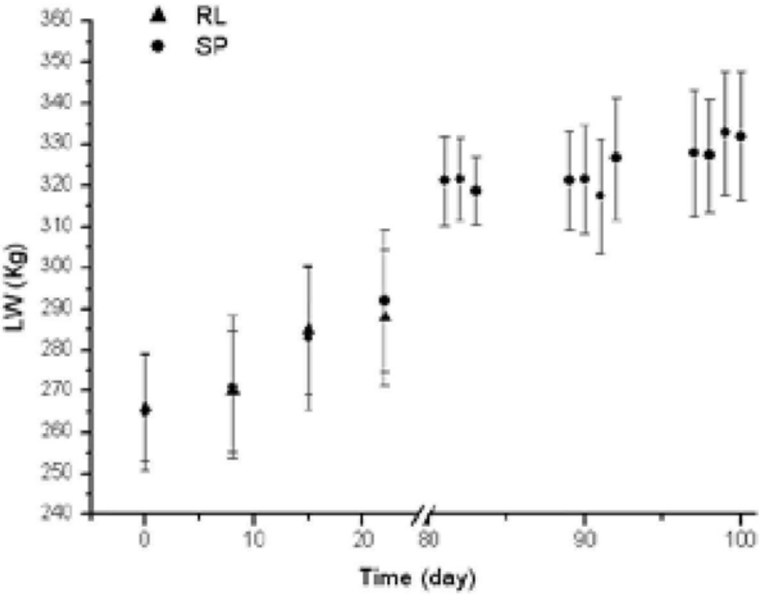


Fig. 2 Average gross liveweights (LW) (kg) of the entire group in each experiment. Day 0 corresponds to 1 December 2005. The bars represent the characteristic width of the LW distribution, which is not related to the precision attributable to the determination of liveweights gain.

Table 3 Samples analysed and average values of methane emission in g/day. RL, Range land paddock; SP, sown pasture paddock.

Experiment 1

	Day		
	12–14 (2nd week)	20–21 (3rd week)	Mean
RL			
n	4	13	
Mean	162	167	162
SD	57	53	41
SP			
n	5	16	
Mean	164	184	177
SD	65	56	49

Experiment 2

	Day							
	88	89	90	91	95	97	98	Mean
n	2	3	4	6	5	5	7	
Mean	167	172	161	155	139	150	201	163
SD	24	81	50	40	49	43	45	49

For our purpose the more relevant parameter is *DE*. The average value for Experiment 1 was 55.9% in the RL paddock and 64.5% in the SP paddock, whereas in Experiment 2 (SP paddock) it was 63.0%. However, in the RL paddock (Experiment 1a) *DE* decreased strongly between days 11 and 18 and then remained low. The decrease might be partially associated with a drought, whose effect in the SP paddock (Experiment 1b) was much less likely because the initial herbage allowance was higher there. On the contrary, we did not observe significant variation of *DE* between the two determinations carried out at the beginning and at the end of Experiment 2. This was probably because the paddock was very large (12 ha), so that the animal stocking rate was much lower than in the paddocks of Experiment 1, and the experiment was performed after and during a period characterised by frequent rainfalls.

Gas samples collected and methane emission

The number of samples successfully collected and analysed per week and the corresponding average methane daily emission E_m are given in Table 3. In the upper part we report the results corresponding to Experiment 1.

An unexpected result is that animals in the RL paddock emitted on average slightly less CH_4 than those in the SP paddock. This point will be discussed in connection with the calculation of the methane yield and after the description of the LW change.

In Table 3 (lower part) we report the number of successfully collected and analysed samples from day 88 of the experiment (27 February) to day 98 (9 March) and the corresponding mean methane emissions. The overall mean value, 163 g/day, was slightly lower in spite of the higher average LW.

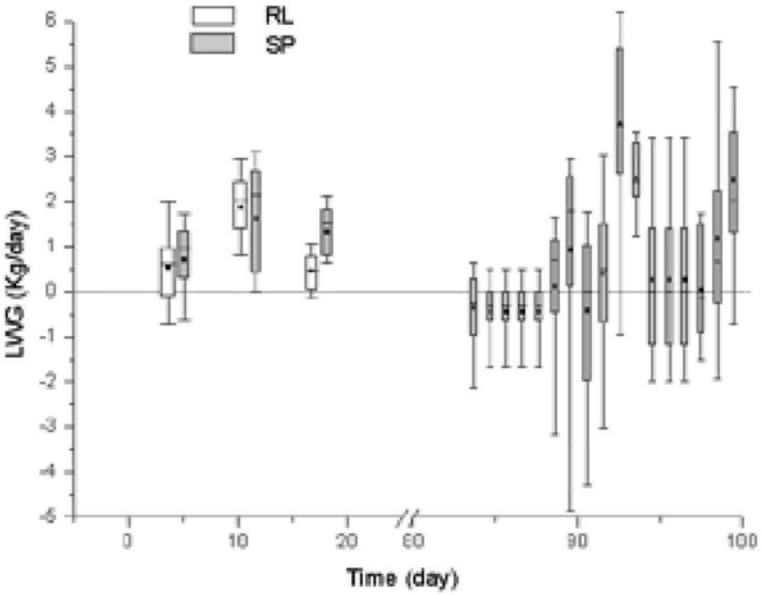


Fig. 3 Liveweight (LWG) gain. The longest vertical bars contain the 5–95% percentile of the LWG values, the rectangles the 25–75% percentile. The short horizontal central bar is the median and the dot is the average value.

Inter-day variation and inter-animal variation are of the same order in both experiments, and range from 10 to 40%. This variation is somewhat higher than that reported elsewhere (see for instance: Lassey et al. 2002; Ulyatt et al. 2002, 2005). Probably this is a consequence of the considerable natural heterogeneity of the herbage in the paddocks.

Liveweights and liveweight changes

In Fig. 2 we report the time dependence of the gross LW averaged over the steers involved in each experiment and the corresponding SD. For Experiment 1 we give separate averages for animals grazing RL and SP. Day 0 corresponds to the first weighing at the beginning of Experiment 1 (1 December 2005) and day 99 to the last weighing at the end of Experiment 2 (10 March 2006) (note that the temporal axis jumps from day 21, end of Experiment 1, to day 81, beginning of Experiment 2). No significant differences were observed between animals with and without PT (the latter not included in the reported averages).

The SD values are representative of the homogeneity of the groups of animals (in fact they give the width of the LW distribution), but they have nothing to do with the uncertainty in the determination of the LWG. Figure 3 gives the LWG (we use 1 day as the time unit throughout all the work) together with some indicative statistical parameters. Note that the values of LWG corresponding to Experiment 1 are assigned to the central day between two consecutive weightings.

In Experiment 2 animals were weighed daily, therefore the LW of consecutive days were affected by variations larger than the daily LWG. For this reason we replaced the measured LW of each day by a moving average calculated with a three-term binomial filter (the use of a five-term filter gave very similar results) and only after we calculated the LWG.

The overall average LWG for the entire experiment was 0.65 kg/day. However, its value changed markedly between periods. In some periods it exceeded 1.5 kg/day, whereas it became negative during the first period of Experiment 2. Moreover, during the third week of Experiment 1, the LWG differed considerably between RL and SP paddocks.

An analysis of variance (ANOVA test) gave 0.99 confidence of the changes of LWG observed in Experiment 1a between the second week and the first and third weeks. A similar analysis gave a 0.95 confidence for the analogous changes in the Experiment 1b. Note that the LWG were similar for both paddocks during the first 2 weeks, showing a strong enhancement from the first to the second week. In the third week the LWG markedly decreased in the RL paddock (Experiment 1a) and only slightly in the SP paddock (Experiment 1b). In summary, during Experiment 1, the LWG differed between the two paddocks only during the last week, when *DE* fell markedly in RL, but remained relatively high in SP.

Figure 3 shows clearly two different periods in Experiment 2, also visible in Fig. 2. In the first, characterised by bad weather conditions, the values of the LWG are slightly negative. In the second, starting around day 88, LWG jumped to positive values whose average was 1.03 kg/day. This value is very similar to the slope of a linear regression of the LW values reported in Fig. 2 for this second period.

As in the first period we did not collect gas samples; in the calculations concerning methane yield we considered only the second period, and we adopted the mean value 1.03 kg/day for the LWG. The oscillations shown in Fig. 3 during this period are of statistical significance. However, owing to the low number of per-day collected samples, we prefer to ignore them in the following analysis.

Methane yield

Methane yield Y_m is defined for a given animal as the ratio between the energetic equivalent E_m of the CH_4 emission and the *GE*. We express these parameters in MJ (the energetic equivalent of 1 g CH_4 is 55.65 kJ). As the direct measurements of *GE* under conditions of extensive grazing is in practice not possible, we had to derive this parameter with an energy requirement model. For this purpose we used the model suggested in IPCC (1996) (where the sex coefficient C_s is unity for steers, the adult LW m_a is 650 kg for Aberdeen Angus males and the activity requirement for grazing animals in a flat zone is assumed to determine a 17% increment of the net energy for maintenance NE_m, so that $C_a = 1.17$.)

We carried out the calculation for weeks 2 and 3 of Experiment 1 assuming mean values for each week in each paddock. As the above expressions are non-linear this is not strictly correct, however it does not make an appreciable difference. Specifically:

(a) The weight *m* corresponding to a given week is 0.96 times the average between LW at the beginning and at the end of the week.

(b) The values of *dm/dt* are 0.96 times the LWG of Fig. 3 (we remind that *t* is measured in days).

(c) The digestibility *DE* of the DM is the average between the values at the beginning and the end of each week (Table 2).

In the case of Experiment 2, the LW is the overall mean between the LW directly measured from day 88 to 99; the LWG is 1.03 (see above). Both magnitudes are multiplied by 0.96 to obtain *m* and *dm/dt*. Finally, the digestibility *DE* is assumed constant and given by the average between the very similar values obtained in days 81 and 104. The support for this assumption is given at the end of the section devoted to herbage composition.

The results obtained for *GE* and Y_m are shown in Table 4, together with *DE*, *dm/dt*, and a parameter, $F = (dm/dt/)E_m$, that is the gained net LW per unit emission, which in this case is expressed in kilograms of CH_4, so that F is dimensionless. This parameter represents a merit factor which may be important for a beef production system with the advantage that it depends only on measurements on the animals.

DISCUSSION

The changes in E_m were small in spite of the considerable variation of *DE*, *dm/dt* and *m* (between Experiments 1 and 2). Besides, if measured during short periods, E_m (i.e., the daily emission of individuals) may lead to wrong conclusions on the methane emission from a production system. For instance, during the third week of Experiment 1 E_m was lower in the RL paddock than in the SP paddock in spite of the marked deterioration of the pasture in the first one. However, when considering F, the relation is

Table 4 Value of gross energy intake (*GE*) and methane yield (Y_m) for the last 2 weeks of Experiment 1 and for Experiment 2. The factor of merit F is in kg/kg. The time unit is 1 day. RL, Range land; SP, sown pasture; *DE*, dry matter digestibility.

Averaged values	Experiment 1 RL		Experiment 1 SP		Experiment 2
Days	8–14	15–22	8–14	15–22	81–99
M (kg)	277	286	277	288	324
$dm/dt = 0.96$ LWG	1.901	0.394	1.670	1.190	0.989
E_m (MJ/day)	9.0	9.3	9.1	10.2	9.0
$F = (dm/dt)$/kg CH_4	11.78	2.36	10.18	6.47	6.07
DE (%)	55.7	49.2	67.1	62.5	63.0
GE (MJ/day)	260.5	166.0	159.4	157.1	154.4
Y_m	0.035	0.056	0.057	0.065	0.058

largely reversed. Another point is the small effect of that deterioration on GE and Y_m. Furthermore, during the second week of Experiment 1 when the pasture deterioration was much less marked, GE was unrealistically high (and Y_m unrealistically low). In fact, the indirect measure which shows the more rational behaviour is the merit factor F. Its value was practically the same in both paddocks during the second week of Experiment 1, then decreased during the third week strongly in RL and less in SP, as can be expected due to the deterioration of the pastures. Finally, F was somewhat lower in Experiment 2 when the LW of the animals (and so the maintenance energy) was larger. To the contrary, some of the values of GE and Y_m, which in our case depend on DE, seem too low.

The prices paid for working under production conditions were the difficulty in defining a representative mean of the dry matter digestibility in such large and rather heterogeneous paddocks, a considerable inter-animal and inter-day variability of the methane emission rate, and a low collection efficiency of gas samples. In fact, although 20 steers were loaded with enteric SF_6 permeation tubes, the total number of gas samples successfully collected and analysed was 76 over 17 days of field work, distributed in two periods (Experiment 1, December 2005, and Experiment 2, February–March 2006). Some of the above problems might have been reduced by enclosing few animals in small well-controlled areas. However, in this first experiment we preferred to face some of the troubles arising from keeping the animals in a true production context.

In our experiments the digestibility DE measured *in vitro* from random DM samples almost certainly differed from the digestibility of the DM actually ingested by the animals. Evidence of selective consumption of herbage during free grazing has been previously reported (see, for instance, Machado et al. 2006). This selection results in an *in vivo* digestibility (DE_e) of the DM actually ingested considerably higher than that measured from randomly selected samples. This difference should be larger the lower the average quality of the pasture.

In experiments on animals maintained in a production system like the Argentinean one, the measurements of DE_e is extremely difficult. Therefore, only to check the plausibility of the approximation, we assumed a dependence of Y_m on DE_e which as a first approximation may be supposed linear. According to published results, the slope for such linear relationship may be estimated by taking Y_m c. 0.03 for $DE_e = 85\%$ (feedlots) and Y_m c. 0.12 for $DE_e = 40\%$ (very low digestible pastures). Now it is possible to obtain indicative values for DE_e from the set of equations $GE = E_m/Y_m(DE_e)$ and $GE = f(DE_e, m, dm/dt)$. The values of DE_e and its increments with respect to DE are given in Table 5 together with the corresponding values of GE and Y_m.

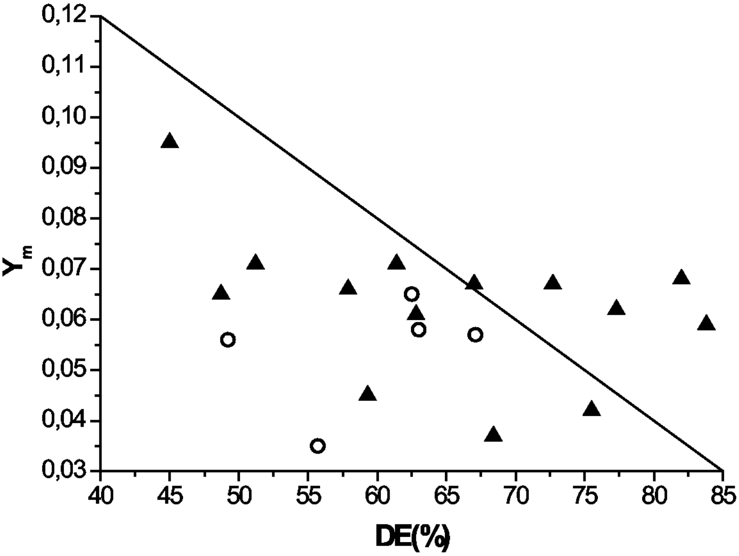
Note that the relative increment of DE_e with respect to DE is about 6% for the SP paddocks, but it is considerable for the RL paddock, where, according to Table 5, consumption was not only selective, but also low, as indicated by the relatively small value of the gross energy.

A comparison with other results published in the literature is not easy because we do not find measurements concerning grazing young steers under production conditions. Besides, we recall that pasture in a large paddock is considerably heterogeneous in our region. Nevertheless, in Fig. 4 we represent Y_m as a function of DE for: (a) our results; (b) the data summarised in table 1 of Lassey (2007), which involve different kinds of cattle (all weighing more than 398 kg); and (c) the straight line used for the evaluation of DE_e. Indeed, the correlation between

Table 5 Dry matter digestibility (DE): digestibility measured in samples of dry matter (DM). DE_e: calculated *in vivo* digestibility. ΔDE represent percentage differences between DE_e and DE. Gross energy intake (GE) percentage: value of the digestibility gross energy intake. Y_{me}: methane yield calculated by assuming a linear relationship Y_{me} versus DE_e. RL, Range land; SP, sown pasture.

Experiment	Days	DE	DE_e	ΔDE (%)	GE_e	Y_{me}
1 (RL)	8–14	55.7	72.5	30.1	162.2	0.056
	15–22	49.2	59.8	21.5	111.8	0.083
1 (SP)	8–14	67.1	71.4	6.41	156.3	0.058
	15–22	62.5	66.6	6.56	149.0	0.069
2	81–99	63.0	66.1	4.92	138.4	0.070

Fig. 4 Methane yield (Y_m) as a function of dry matter digestibility (*DE*) for our results (in circles) and the data summarised in table 1 of Lassey (2007), which involve different kind of cattle (triangles; see specific references in the work). The straight line represents the linear relationship used for the evaluation of DE_e.



Y_m and *DE* is affected by a strong dispersion. However, our results show on average lower values of Y_m, likely due to the aforementioned selectivity of the ingest.

CONCLUSIONS

We report here the first measurements of methane emission from a homogeneous group of Aberdeen Angus young steers freely grazing in paddocks of a typical farm of the Argentinean beef cattle system. Measurements were performed in summer periods and 76 gas samples were successfully collected and analysed. We also measured some parameters related with the varying pasture allowance and quality in the paddocks where the animals were allocated. The liveweight change is relevant because the animals were at the peak of their growth. The first result is that the mean methane emission is little affected by changes of the pasture quality, liveweight or liveweight gain. To the contrary, the liveweight gain and a factor of merit defined as the net liveweight gain per kilogram of methane emitted, which are significant for a production system, depend strongly on the pasture quality and very likely also on other factors. For instance, the bad weather conditions prevailing at the beginning of the second experiment coincided with a near null liveweight gain (unfortunately the methane emission could not be measured in that period).

Our results suggest that the digestibility of the dry matter actually ingested by the animals is higher than the average value obtained from the analysis of samples taken from the field.

This work showed that the application of the SF_6 tracer technique to study methane emission by cows under realistic production conditions typical of the Argentinean beef system is possible and useful. However, it would be important to develop collection sets based on small metallic vessels with air inflow regulators suitable for a many-day collection period. In fact, when studying emission from growing animals under real production conditions it seems very important to take the measurements during a period of few months.

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