

PAPER

Methane yield from dry and lactating cows diets in the Po Plain (Italy) using an *in vitro* gas production technique

Mario Pirondini,¹ Luca Malagutti,¹
Stefania Colombini,¹ Paola Amodeo,²
Gianni Matteo Crovetto¹

¹Dipartimento di Scienze Agrarie e Ambientali, Università di Milano, Italy
²Associazione Regionale Allevatori della Lombardia, Crema, Italy

Abstract

The aim of the study was to measure total gas and methane (CH₄) production from 30 total mixed rations (TMRs) fed to dry and lactating cows in 20 commercial dairies in the Po Plain (Italy). Samples were analysed for chemical composition, *in situ* 48 h fibre digestibility (NDFD) and *in vitro* gas production (GP) and CH₄ concentration at 24 h of incubation. NDFD of TMRs from dry and lactating cows was identical (52.1%; P=0.995). The TMRs fed to dry and lactating cows differed for GP (43.0 and 54.4 mL/200 mg DM, respectively; P<0.001) and CH₄ (7.24 and 8.85 mL/200 mg DM, respectively; P=0.001), but not for CH₄ as percentage of GP (24.3 and 23.7%, respectively; P=0.286). The data were analysed dividing the TMRs into quartiles depending on starch:ADF ratio; the average ratios of the groups 1, 2, 3 and 4 were 37, 77, 116 and 138, respectively. Increasing starch:ADF ratio determined a higher GP: 42.2, 51.4, 55.1 and 56.2 mL/200 mg DM for groups 1, 2, 3 and 4, respectively (P<0.001), whilst CH₄ (mL/200 mg DM) was lower (P<0.001) for group 1 (7.12) in comparison with the others (8.82 on average). Acetate (% on total VFA) decreased for increasing starch:ADF ratio (P=0.009), whereas butyrate tended to increase (from 8.11 to 9.23% on total VFA; P=0.069) and the acetate:propionate ratio to decrease (from 3.35 to 3.09; P=0.082). The lack of a higher CH₄ concentration in GP from diets richer in fibre might be attributed mainly to the relatively short time of incubation.

Introduction

Methane (CH₄) is one of the most important greenhouse gases (GHG) emitted from anthro-

pogenic sources with a contribute to climatic change and global warming 21 times more effective than carbon dioxide (CO₂) (IPCC, 2007). Agriculture accounts for approximately 10 to 12% of the estimated anthropogenic greenhouse effect, producing about 45% of overall anthropogenic CH₄ emissions, with a wide range of uncertainty in the estimates of both the agricultural contribution and the anthropogenic total (IPCC, 2007). Domestic ruminants are the main responsible of these emissions, which derive primarily from enteric fermentations (Ellis *et al.*, 2007) but also from the fermentation of organic matter in manure. Methane emissions from gastrointestinal tract are an indirect result of ruminal fermentation processes performed by microorganisms that digest and ferment carbohydrates into energy sources such as volatile fatty acids (VFA) (Getachew *et al.*, 2005b; Hariadi and Santoso, 2010). Ruminal CH₄ production is energetically a wasteful process (Getachew *et al.*, 2005b), since the proportion of feed converted to CH₄ represents a loss of approximately 2% to 12% of the gross energy intake (Johnson and Johnson, 1995). In the European Union approximately two-thirds of annual regional methane emissions, amounting to about 6.8 million tonnes, have been attributed to enteric fermentation in ruminants (Moss *et al.*, 2000). Among European countries, Italy has a legally binding commitment under the Kyoto Protocol to reduce GHG emissions by 6.5% below base-year levels, on average, over the first commitment period, 2008-2012. There is still uncertainty about the real impact of animal husbandry on GHG: from the first very high estimates (18%) of Steinfeld *et al.* (2006) lower impacts (12 to 13%) were reported by IPCC (2007), even lower (3 to 8%) by Capper *et al.* (2009) and eventually to an impact of 3% reported by Pulina *et al.* (2011) for Italy.

The amount of enteric CH₄ production is determined by many factors including: dry matter intake (Reynolds *et al.*, 2010; Tamburini *et al.*, 2010), diet characteristics such as supplementation with lipids (Grainger and Beauchemin, 2011) and type and level of carbohydrates fermented (Ellis *et al.*, 2007), technological processes applied to feeds, and management practices that manipulate ruminal population (number of protozoa and methanogens) (Odongo *et al.*, 2007). The adoption of these factors can reduce CH₄ production improving nutrient and energy utilization efficiency and decreasing environmental pollution. Hence, it is essential to be able to quantify the CH₄ produced from ruminal fermentation of different diets fed to dairy cows. Methane emissions are determined using both

Corresponding author: G. Matteo Crovetto,
Dipartimento di Scienze Agrarie e Ambientali,
Università degli Studi di Milano, via Celoria 2,
20133 Milano, Italy.
Tel. +39.02.50316433 - Fax: +39.02.50316434.
E-mail: matteo.crovetto@unimi.it

Key words: Methane, Cow, TMR, *In vitro*.

Acknowledgments: this research was conducted with support from EU Research Project LIFE 09 ENV/IT/0214 Gas-Off.

Received for publication: 25 May 2012.
Revision received: 19 July 2012.
Accepted for publication: 31 July 2012.

This work is licensed under a Creative Commons Attribution NonCommercial 3.0 License (CC BY-NC 3.0).

©Copyright M. Pirondini *et al.*, 2012
Licensee PAGEPress, Italy
Italian Journal of Animal Science 2012; 11:e61
doi:10.4081/ijas.2012.e61

in vivo and *in vitro* assays. However, direct techniques are expensive, require complex equipment and are labour expensive and time consuming. Consequently, *in vitro* gas production (GP) method is an alternative relatively labour saving and affordable technique (Getachew *et al.*, 2005a) which allows different diets to be tested simultaneously, alone or in presence of additives and inhibitors, for their effect on methanogenesis.

Due to lack of measured data on methane enteric emission by dairy cows in the Po Plain (Lombardy, Italy), aim of this study was to measure CH₄ production from total mixed rations (TMRs) fed to dairy cows in commercial dairies in this area using an *in vitro* GP technique.

Materials and methods

Sample collection and preparation

Thirty TMRs (22 and 8 samples for lactating and dry cows, respectively) were collected from 20 Italian Friesian commercial dairy farms in the Po plain (Italy) in the period November-December 2010. Average milk yield of cows in the selected farms was 30±4.6 kg/d. Samples were dried at 55°C in a forced air oven for 48 h and then ground to pass a 1 mm sieve using a Wiley mill (Pulverisette, Fritsch, Idar-Oberstein, Germany).

Chemical analysis, dry matter and fibre digestibility

Dry matter (DM) was determined following the AOAC procedure (AOAC, method 945.15, 1995), and organic matter was calculated as weight lost upon ignition at 600°C (AOAC, method 942.05, 1995). The crude protein (CP) content was determined by the macro-Kjeldahl technique (AOAC, method 984.13, 1995) using a 2300 Kjeltac Analyzer Unit (FOSS, Hillerød, Denmark). Ether extract was determined following the method 920.29 of the AOAC (1995). Neutral detergent fibre (NDF) was determined according to Mertens (2002), with addition of sodium sulphite and α -amylase to the neutral detergent solution. Acid detergent fibre (ADF), determined not sequentially to NDF, and acid detergent lignin (ADL) were calculated according to the method of Van Soest *et al.* (1991) using the Ankom 200 fibre apparatus (ANKOM Technology Corporation, Fairport, NY). Fibre fractions are reported on an ash-free basis. Neutral detergent insoluble crude protein and acid detergent insoluble crude protein were determined according to Licitra *et al.* (1996). Starch content was determined using Megazyme kit K-TSTA (Megazyme International Ireland Ltd., Wicklow, Ireland) for total starch assay procedure (AOAC, method 996.11, 1998). Ruminant NDF digestibility (NDFD) was determined using an *in situ* assay as reported by Spanghero *et al.* (2010) with an incubation time of 48 h. Each sample was weighed (250 mg as fed) in duplicate into Ankom F57 filter bags (ANKOM Technology Corporation, Fairport, NY, USA). Samples were incubated in 2 incubation runs repeated on different days and using for each sample 2 rumen fistulated dry Italian Friesian cows fed a ration composed of meadow hay, flaked maize and a commercial protein concentrate (forage:concentrate ratio 65:35 on DM) twice daily. After 48 h of incubation, bags were collected from the rumen, washed thoroughly using cold tap water and then analysed using the Ankom 200 fibre apparatus (ANKOM Technology Corporation, Fairport, NY) according to Mertens (2002), with addition of sodium sulphite and α -amylase to the neutral detergent solution.

Animals on trial were handled as outlined by the guidelines of the 116/92 Italian law about animal welfare on experimental animals (Italian Regulation, 1992).

In vitro gas production and calculations of energetic value of rations

Gas production was determined using a semi-automatic system (Theodorou *et al.*, 1994), based on the measurement of the head-

space gas pressure in the incubation bottles. Samples (250 mg as fed) were weighed in duplicate into 120 mL serum bottles. Buffered mineral solution and reducing solution were prepared according to Menke and Steingass (1988), stored in a water-bath at 39°C and purged with CO₂. Rumen fluid was collected before the morning feeding from two fistulated dry Italian Friesian cows fed as previously described. At the barn rumen fluid was squeezed through a cheesecloth layer and stored into a pre-warmed thermos flask, transferred to the laboratory, strained through four layers of cheesecloth and flushed with CO₂. The rumen fluid was added to the buffered mineral solution (rumen fluid:buffer solution ratio=1:2) with constant stirring, while maintained at 39°C. Thirty mL of inoculum was dispensed into the bottles containing the TMR samples, for a corresponding headspace volume of 90 mL. The procedures were conducted under anaerobic conditions, flushing the bottle headspace with CO₂. The serum bottles were closed hermetically with rubber tops and placed in a shaking water-bath (75 RPM) at 39°C for 24 h. Each sample was analysed in 2 incubation runs. Headspace pressure was recorded after 2, 4, 6, 8, 10 and 24 h of incubation using a digital manometer (model 840082, Sper Scientific, Scottsdale, AZ, USA), avoiding that headspace pressure exceeded 48 kPa to preserve the normal microbial activity, as reported by Theodorou *et al.* (1994). The gas pressure data recorded at each time-point were converted to moles of gas using the ideal gas law ($n=p*(V/R*T)$), where: n: gas produced (mol), p: pressure (kPa), V: headspace volume in bottles (L), R: gas constant (8.314 L*kPa*K⁻¹*mol⁻¹, T: temperature (K)), converted to millilitres of gas and then cumulated to obtain GP at 24 h of incubation. The GP values at 24 h were corrected for blanks and standard feeds included in each run in order to calculate the rumen organic matter digestibility (OMD, %) and the energetic value of TMRs (NE_L, Mcal/kg DM) according to Menke and Steingass (1988). At each reading time, after gas pressure data recording, a fixed-volume sample of gas (5 mL/bottle) was also collected for subsequent methane analysis using gas-tight syringes fitted with needles through the bottle top. After collection, remaining gas was released by needles and the pressure was brought back to atmospheric value.

Methane measurement

The gas composition of the headspace was determined by injecting 5 mL of gas into an Agilent 3000A micro GC gas chromatograph (Agilent Technologies, Santa Clara, CA, USA)

using N as carrier. An external standard mixture of CO₂ and CH₄ prepared by SIAD SpA (Bergamo, Italy) was used for instrument calibration. Peak areas were calculated by automatic integration. The CH₄ volume (mL) produced between two time points and final cumulated volume were calculated as reported by Tavendale *et al.* (2005).

Ruminal volatile fatty acids determination

At the end of the incubation period, 10 mL of inoculum was sampled and clarified by centrifugation at 3500 × g for 10 min. After centrifugation 5 mL of supernatant was sampled and added with 25% meta-phosphoric acid at a ratio of 5 parts of inoculum to 1 part of acid. The mixture was covered, held at room temperature for 30 min and centrifuged again at 3500 × g for 10 min. A 1 mL aliquot of supernatant was pipetted into a GC auto-sampler vial containing 100 µL of internal standard solution (2 mL of 2-ethylbutyric acid in 15 mL of 90% ethanol brought to a final volume of 500 mL with deionized water), sealed and placed in an auto-sampler tray. Volatile fatty acid concentrations were determined using a Varian 3800 gas chromatograph (Varian Chromatography Systems, Walnut Creek, CA, USA) using a Nukol fused silica capillary column (30 m length; 0.25 mm diameter; 0.25 µm film thickness; Supelco, Bellefonte, PA, USA). Initial column temperature was 80°C for 2 min, increased at a rate of 5°C/min to 100°C maintained for 1 min, increased at a rate of 7°C/min to 140°C and finally increased at a rate of 15°C/min to a final temperature of 200°C, with a total running time of 21 min. Injector and FID temperatures were 220°C and 250°C respectively, with a carrier gas (He) flow of 4 mL/min and a split ratio of 50:1. VFA were identified and quantified from chromatograph peaks areas using calibration with internal standard, according to a modified procedure introduced by Moore *et al.* (2002).

Statistical analysis

Statistical analysis was carried out using one-way variance analysis procedure of IBM SPSS Statistics 18 (IBM Corporation, Armonk, NY, USA). Data deriving from biological analyses were analysed considering the type of TMR (dry vs lactating) as factor. The Pearson correlation between the starch:ADF ratio of the all 30 diets and the GP and the CH₄ production was first studied. Then the entire population (30 TMRs) was divided into quartiles considering starch:ADF ratio as parameter to take into account the effects of both rapidly and slowly

fermentable carbohydrates. Data were analysed considering the quartile as main factor (fixed effect), the period (incubation run) as random effect, and their interaction. Differences among means with $P < 0.05$ were declared significant. Subsequent *post-hoc* multiple comparisons were performed using Bonferroni test (equal variances assumed) or Dunnett (T3) test in case of heteroskedasticity of variances.

Results and discussion

Diets composition and chemical analysis

The feeds used to formulate dry cows TMRs were primarily meadow hay, corn silage, wheat straw and protein concentrate (39 ± 14.8 , 32 ± 2.32 , 26 ± 12.5 and $14 \pm 9.68\%$ of total DM, respectively). For lactating TMRs there was a wide range in terms of feeds used and levels of inclusion. Corn silage ($29 \pm 7.60\%$ of total DM), corn (both ground and high moisture, 15 ± 5.25 and $14 \pm 4.74\%$ of total DM, respectively), protein concentrate ($20 \pm 8.63\%$ of total DM) and soybean meal ($12 \pm 5.99\%$ of total DM) were the main ingredients included in the majority of the TMRs fed to lactating cows. The average chemical analysis of the TMRs fed to dry and lactating cows is reported in Table 1. The CP content was 11.5 ± 3.07 and $15.6 \pm 1.73\%$ DM in dry and lactating TMRs, respectively and it seems to be fairly low as required by the need to meet the European Union Nitrate Directive constraints (European Commission, 1991). The average NDF content was 49.2 ± 5.27 in dry TMRs, whereas in lactating TMRs ranged from 25.5 and 41.3, with a mean value of $32.1 \pm 4.17\%$ DM basis. Starch content of lactating TMRs ($23.5 \pm 4.41\%$ on DM) is slightly lower than the level normally registered (28% on DM) in the Po plain area for high producing cows (Crovetto and Colombini, 2010), but non-fibrous carbohydrate (NFC) content ($42.4 \pm 2.93\%$ on DM) is consistent with that found in previous experiments (Getachew *et al.*, 2005b; Masoero *et al.*, 2006).

The diets for both groups appear well balanced to meet the nutritional requirements of the animals in the first phase of the dry period and adequate for lactating cows producing 30 kg milk daily, on average (Fox *et al.*, 2004).

Nutritive value and methane production of the total mixed rations for dry and lactating cows

The different composition and analysis of

the two groups of TMRs (dry and lactating) significantly influence GP, OMD and consequently the energetic value (Table 2). There were differences between dry and lactating TMRs in total GP at 24h of incubation ($P < 0.001$) and in CH_4 production, expressed as mL/200 mg DM ($P \leq 0.001$).

The higher CH_4 emission of TMRs for lactation is explained by the higher starch and NFC contents in comparison with the TMRs for dry animals. Higher CH_4 production is normally associated with fibre fermentation, however, for highly digestible feeds, such as TMRs for lactation, a higher quantity of CH_4 is produced

in early hours of fermentation. In the present experiment GP and CH_4 productions were registered at 24 h, a time sufficient for a complete fermentation of the readily fermentable carbohydrates, but not for the fibrous fractions. These results are consistent with those reported by Getachew *et al.* (2005a) who found a positive correlation between CH_4 production and organic matter, NFC, dNDF, and DM digestibility in the first 24 h of *in vitro* incubation. Similarly Lee *et al.* (2003) registered a comparative higher CH_4 production for grains among other feed ingredients rich in fibre or protein or oil, that might be attributed to the high con-

Table 1. Chemical composition of total mixed rations fed to dry and lactating cows.

	Dry				Lactating			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Dry matter, %	62.4	10.9	47.8	77.5	49.9	5.01	35.3	56.4
Ash, % DM	9.19	1.12	7.70	11.5	7.00	0.69	6.13	8.32
Crude protein, % DM	11.5	3.07	8.12	15.7	15.6	1.73	11.8	18.6
Ether extract, % DM	2.39	0.50	1.89	3.32	3.76	0.83	2.75	5.49
NDF, % DM	49.2	5.27	45.9	61.8	32.1	4.17	25.5	41.3
NDFIP, % DM	2.63	0.68	1.75	3.73	2.01	0.73	1.21	4.60
NDFIP, % CP	23.6	6.46	14.7	33.4	13.0	4.91	7.21	30.4
ADF, % DM	31.7	3.82	27.6	40.2	21.1	2.83	15.0	26.5
ADL, % DM	4.83	0.75	3.68	5.88	3.57	0.76	2.40	5.89
Starch, % DM	12.5	4.29	5.89	19.4	23.5	4.41	16.1	33.4
NFC, % DM	28.4	4.76	18.4	35.3	42.4	2.93	35.6	47.4
Starch:NDF, %	26.0	9.88	9.53	42.3	75.4	21.6	38.9	128
Starch:ADF, %	40.4	15.2	14.7	66.0	115	35.7	60.5	223

SD, standard deviation; DM, dry matter; NDF, neutral detergent fibre; NDFIP, Protein bound to the NDF fraction; ADF, acid detergent fibre; ADL, acid detergent lignin; NFC, non-fibrous carbohydrate.

Table 2. Total gas and methane production, organic matter and neutral detergent fibre digestibility, and volatile fatty acids production of total mixed rations fed to dry and lactating cows.

	Dry	Lactating	SE	P
GP, mL/200 mg DM	43.0	54.4	1.11	<0.001
Methane ^o , mL/200 mg DM	7.24	8.85	0.19	0.001
Methane ^o , % total GP	24.3	23.7	0.22	0.286
OMD, %	64.3	74.8	1.03	<0.001
NEL, Mcal/kg DM	1.25	1.62	0.04	<0.001
NDFD, %	52.1	52.1	1.04	0.995
dNDF, % DM	25.6	16.8	0.95	<0.001
VFA, mmol/L	49.2	47.7	0.99	0.516
Acetate, mmol/L	34.9	33.2	0.77	0.340
Acetate, % VFA	70.6	69.3	0.26	0.025
Propionate, mmol/L	10.4	10.3	0.21	0.750
Propionate, % VFA	21.3	21.6	0.20	0.448
Butyrate, mmol/L	3.89	4.25	0.09	0.066
Butyrate, % VFA	8.14	9.08	0.17	0.011
Acetate:Propionate	3.34	3.24	0.04	0.314

GP, gas production (at 24 h of incubation corrected for blank and standard feeds gas production); DM, dry matter. ^oCumulated methane production at 24 h of incubation; the percentage on total GP is referred to the raw GP, not corrected for standard feeds gas production. OMD, organic matter digestibility (calculated according to Menke and Steingass GP technique, 1988); NEL, net energy of lactation (stimated using equation no. 171 for compounds and roughage feeds, Menke and Steingass, 1988); NDFD, neutral detergent fibre digestibility; dNDF, digestible neutral detergent fibre; VFA, volatile fatty acids.

tent of easily fermentable sugars, starch and pectins of grains. Similar results were obtained by Navarro-Villa *et al.* (2011) who found an increase in CH₄ output with feeds rich in rapidly fermentable carbohydrates.

Unexpectedly, no difference was observed in the percentage of CH₄ of total GP (24.3±1.32 and 23.7±1.18 for dry and lactation TMRs, respectively; P=0.286). Consistently with the present results, a study of Getachew *et al.* (2005b) did not show any difference in CH₄ percentage between 7 diets for lactation in the first 24 hours of *in vitro* incubation, although significant differences among diets and an overall increase in CH₄ proportion were registered at 48 and 72 hs. No differences were detected among groups for NDFD (P=0.995) (Table 2), however, due to the higher NDF content in dry cows TMRs, digestible NDF (dNDF, % on DM) in this group resulted significantly higher (P<0.001). This resulted in a significant higher acetic acid concentration, expressed as percentage of total VFA produced, for dry cows TMRs (P=0.025) although the difference between the two groups was numerically quite small. On the contrary, butyric acid concentration, as percentage of total VFA, resulted significantly higher for lactating cows TMRs. No significant difference between groups was observed for the acetate:propionate ratio (P=0.314) (Table 2).

Methane production and dietary starch:ADF ratio

The period (random effect) and the interaction period x starch:ADF ratio were never significant and hence removed from the statistical model. Considering the entire population of TMR tested, divided into quartiles using the starch:ADF ratio as parameter, significant differences among groups in total GP (P<0.001) and in CH₄ production, expressed as mL/200 mg DM (P<0.001) were observed (Table 3). The volume of CH₄ produced increased significantly for increasing starch:ADF ratio, confirming the positive effect of starch on methanogenesis within the first 24 h of *in vitro* incubation. This is confirmed by the highly significant correlation between the starch:ADF ratio and the GP (r=0.87; P<0.001) and the volume of CH₄ produced (r=0.66; P<0.001). Similarly, Singh *et al.* (2011), in an *in vitro* study, showed that dry roughages with a higher content of non-structural and soluble carbohydrates produced more CH₄ than roughages with higher levels of fibre. Overall, the average volume of CH₄ produced after 24 h of incubation was consistent with the values reported by Lee *et al.* (2003) for cereal grains

(6.9 to 11.6 mL/200 mg DM).

As previously observed, no differences were detected for CH₄ as percentage of total GP. This is confirmed by the low correlation coefficient (r=-0.28; P=0.138) between the starch:ADF ratio and the percentage of CH₄. The lack of difference can be partially due to the short incubation time. Furthermore *in vitro* fermentation is essentially a type of enrichment culture, in which the particular set of environmental conditions used (pH, substrate type and concentration, presence of growth stimulants or inhibitors, *etc.*) are likely to set the stage for preferential rate or extent of growth of some microbial species over other species present in the original *inoculum* (Madigan *et al.*, 2000). The strongly buffered *in vitro* system also did not determine the low pH that is associated with inhibition of fibrolytic bacteria (Argyle and Baldwin, 1988) and methanogens (Van Kessel and Russell, 1996). Russel (1998) showed that CH₄ production *in vivo* decreased dramatically at pH below 6.3. In our experiment, as in most of *in vitro* studies, the use of a buffer solution avoided such a drop in pH which was maintained in the range of 6.5-7.0, optimal for the fermentation of the cellulolytic microbes (McGeough *et al.*, 2011). In the present experiment all diets in every incubation run were treated with the same *inoculum*, therefore the comparison between treatments

is valid. However, a possible interaction between *inoculum* characteristics and the diet fed to the donor animals can be expected. Demeyer and Fievez (2000) reported that a greater proportion of cellulolytic bacteria and methanogenic *Archea* is expected in rumen fluid obtained from ruminants fed high forage diets. Consequently, the *in vitro* fermentation pattern can be indirectly influenced by the diet of the donor animals. Martinez *et al.* (2010), in a study on 24 h *in vitro* methanogenesis, found that the use of an *inoculum* obtained from animals fed diets with a 30:70 forage:concentrate ratio on DM determined a higher CH₄ production in comparison with an *inoculum* obtained from animals fed diets with a 70:30 forage:concentrate ratio. The NDFD did not differ among groups but the proportion of dNDF significantly decreased (P<0.001) as the starch:ADF ratio increased, due to a subsequent lower NDF content. As a consequence acetic acid as percentage of total VFA slightly decreased from 70.7±1.67 (group 1, lowest starch:ADF ratio) to 68.5±0.82% (group 4, highest starch:ADF ratio) (P=0.009), whilst butyric acid percentage numerically increased with increasing starch:ADF ratio. The proportion of propionic acid did not differ among groups; consequently only a tendency (P=0.082) in acetate:propionate ratio decrease was registered as starch:ADF ratio increased (Table 3).

Table 3. Total gas and methane production, organic matter and neutral detergent fibre digestibility, and volatile fatty acids production of total mixed rations divided into quartiles using starch:ADF as parameter.

	Group 1	Group 2	Group 3	Group 4	SE	P
Starch:ADF, %	37	77	116	138		
GP, mL/200 mg DM	42.2 ^c	51.4 ^b	55.1 ^{ab}	56.2 ^a	1.51	<0.001
Methane ^o , mL/200 mg DM	7.12 ^b	8.54 ^a	9.04 ^a	8.87 ^a	0.19	<0.001
Methane ^o , % total GP	24.2	24.2	23.8	23.2	0.22	0.382
OMD, %	63.9 ^c	71.5 ^b	75.6 ^a	76.5 ^a	1.51	<0.001
NEL, Mcal/kg DM	1.23 ^c	1.51 ^b	1.63 ^a	1.69 ^a	0.06	<0.001
NDFD, %	52.1	51.5	52.7	52.0	3.21	0.985
dNDF, % DM	25.9 ^a	19.1 ^b	16.5 ^b	15.3 ^b	1.82	<0.001
VFA, mmol/L	49.4	48.6	47.6	46.7	3.00	0.820
Acetate, mmol/L	35.1	34.2	33.1	32.2	2.29	0.596
Acetate, % VFA	70.7 ^a	70.2 ^{ab}	69.3 ^{ab}	68.5 ^b	0.64	0.009
Propionate, mmol/L	10.4	10.2	10.2	10.3	0.64	0.976
Propionate, % VFA	21.2	21.1	21.5	22.3	0.55	0.136
Butyrate, mmol/L	3.89	4.17	4.31	4.21	0.25	0.382
Butyrate, % VFA	8.11	8.75	9.19	9.23	0.45	0.069
Acetate:Propionate	3.35	3.36	3.26	3.09	0.12	0.082

GP, gas production (at 24 h of incubation corrected for blank and standard feeds gas production); DM, dry matter. ^oCumulated methane production at 24 h of incubation; the percentage on total GP is referred to the raw GP, not corrected for standard feeds gas production. OMD, organic matter digestibility (calculated according to Menke and Steingass GP technique, 1988); NEL, net energy of lactation (stimated using equation no. 17f for compounds and roughage feeds, Menke and Steingass, 1988); NDFL, neutral detergent fibre digestibility; dNDF, digestible neutral detergent fibre; VFA, volatile fatty acids. a,b,cValues on the same row with different superscript differ significantly (P<0.05).

Conclusions

In the present experiment methane production of different TMRs resulted positively related to the starch and the NE_L concentrations. Unexpectedly, CH₄ production as a percentage of total GP was not influenced by diet characteristics. This might be attributed to the short incubation time, to the characteristics of the *inoculum* and to the methodology applied, which hampered an effective simulation of rumen fermentation.

The long-term *in vivo* technique (e.g., with respiration chambers) is the most accurate in determining the CH₄ production, but it is very cumbersome, expensive and time consuming. On the contrary, the *in vitro* technique, despite some limitations, permits a precise prediction of the fermentation pattern.

References

- AOAC, 1995. Official Methods of Analysis of the Association of Official Analytical Chemists. 15th ed., Washington, DC, USA.
- AOAC, 1998. Official Methods of Analysis, 16th ed., Association of Official Analytical Chemists, Washington, DC, USA.
- Argyle, J.L., Baldwin, R.L., 1988. Modeling of rumen water kinetics and effects of rumen pH changes. *J. Dairy Sci.* 71:1178-1188.
- Capper, J.L., Cady, R.A., Bauman, D.E., 2009. Demystifying the environmental sustainability of food production. pp 174-190 in *Proc. Int. Cornell Nutrition Conf.*, East Syracuse, NY, USA.
- Crovetto, G.M., Colombini, S., 2010. Feeding and nitrogen excretion in dairy cattle. In: G.M. Crovetto and A. Sandrucci (eds.) *Allevamento animale e riflessi ambientali. Fondazione Iniziative Zooprofilattiche e Zootecniche*, Brescia, Italy, pp 27-54.
- Demeyer, D., Fievez, V., 2000. Ruminants et environment: la méthanogénèse (Ruminants and environment: methanogenesis). *Ann. Zootech.* 49:95-112.
- Ellis, J.L., Kebreab, E., Odongo, N.E., McBride, B.W., Okine, E.K., France, J., 2007. Prediction of methane production from dairy and beef cattle. *J. Dairy Sci.* 90:3456-3467.
- European Commission, 1991. Directive of the Council of December 12 concerning the protection of waters against pollution caused by nitrates from agricultural sources, 91/676/EEC. In: *Official Journal L* 375, 31/12/1991, pp 1-8.
- Fox, D.G., Tedeschi, L.O., Tylutki, T.P., Russell, J.B., Van Amburgh, M.E., Chase, L.E., Pell, A.N., Overton, T.R., 2004. The Cornell net carbohydrate and protein system model for evaluating herd nutrition and nutrient excretion. *Anim. Feed Sci. Tech.* 112:29-78.
- Getachew, G., DePeters, E.J., Robinson, P.H., Fadel, J.G., 2005a. Use of an *in vitro* rumen gas production technique to evaluate microbial fermentation of ruminant feeds and its impact on fermentation products. *Anim. Feed Sci. Tech.* 123:547-559.
- Getachew, G., Robinson, P.H., DePeters, E.J., Taylor, S.J., Gisi, D.D., Higginbotham, G.E., Riordan, T.J., 2005b. Methane production from commercial dairy rations estimated using an *in vitro* gas technique. *Anim. Feed Sci. Tech.* 123:391-402.
- Grainger, G., Beauchemin, K.A., 2011. Can enteric methane emissions from ruminants be lowered without lowering their production? *Anim. Feed Sci. Tech.* 166-167:308-320.
- Hariadi, B.T., Santoso, B., 2010. Evaluation of tropical plants containing tannin on *in vitro* methanogenesis and fermentation parameters using rumen fluid. *J. Sci. Food Agric.* 90:456-461.
- Intergovernmental Panel on Climate Change, 2007. *Climate Change 2007: Mitigation of climate change. Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge Univ. Press, Cambridge, UK.
- Italian Regulation, 1992. Application of the Council Directive (EEC) No. 86/609 regarding the protection of animals used for experimental and other scientific purposes. *LD 116/1992*. In: *Official Journal No.* 294, 18/2/1992, pp 5-24.
- Johnson, K.A., Johnson, D.E., 1995. Methane emissions from cattle. *J. Anim. Sci.* 73:2483-2492.
- Lee, H.J., Lee, S.C., Kim, J.D., Oh, Y.G., Kim, K., Kim, C.W., Kim, K.J., 2003. Methane production potential of feed ingredients as measured by *in vitro* gas test. *Asian-Aust. J. Anim. Sci.* 16:1143-1150.
- Licitra, G., Hernandez, T.M., Van Soest, P.J., 1996. Standardization of procedures for nitrogen fractionation of ruminant feeds. *Anim. Feed Sci. Tech.* 57:347-358.
- Madigan, M.T., Martinko, J.M., Parker, J., 2000. *Brock biology of microorganisms*. Prentice Hall Publ., Upper Saddle River, NJ, USA.
- Martinez, M.E., Ranilla, M.J., Tejido, M.L., Saro, C., Carro, M.D., 2010. The effect of the diet fed to donor sheep on *in vitro* methane production and ruminal fermentation of diets of variable composition. *Anim. Feed Sci. Tech.* 158:126-135.
- Masoero, F., Moschini, M., Fusconi, G., Piva, G., 2006. Raw, extruded and expanded pea (*Pisum sativum*) in dairy cows diets. *Ital. J. Anim. Sci.* 5:237-247.
- McGeough, E.J., O'Kiely, P., O'Brien, M., Kenny, D.A., 2011. An evaluation of the methane output associated with high-moisture grains and silages using the *in vitro* total gas production technique. *Anim. Prod. Sci.* 51:627-634.
- Menke, K.H., Steingass, H., 1988. Estimation of the energetic feed value obtained from chemical analysis and *in vitro* gas production using rumen fluid. *Anim. Res. Dev.* 28:7-55.
- Mertens, D.R., 2002. Gravimetric determination of amylase-treated neutral detergent fiber in feeds using refluxing in beakers or crucibles: collaborative study. *J. AOAC Int.* 85:1217-1240.
- Moore, J.A., Poore, M.H., Luginbuhl, J.M., 2002. By-product feeds for meat goats: Effects on digestibility, ruminal environment, and carcass characteristics. *J. Anim. Sci.* 80:1752-1758.
- Moss, A.R., Jouany, J.P., Newbold, J., 2000. Methane production by ruminants: its contribution to global warming. *Ann. Zootech.* 49:231-253.
- Navarro-Villa, A., O'Brien, M., Lopez, S., Boland, T.M., O'Kiely, P., 2011. Modifications of a gas production technique for assessing *in vitro* rumen methane production from feedstuffs. *Anim. Feed Sci. Tech.* 166-167:163-174.
- Odongo, N.E., Bagg, R., Vessie, G., Dick, P., Or-Rashid, M.M., Hook, S.E., Gray, J.T., Kebreab, E., France, J., McBride, B.W., 2007. Long-term effects of feeding monensin on methane production in lactating dairy cows. *J. Dairy Sci.* 90:1781-1788.
- Pulina, G., Dias Francesconi, A.H., Mele, M., Ronchi, B., Stefanon, B., Sturaro, E., Trevisi, E., 2011. Sfamare un mondo di nove miliardi di persone: le sfide per una zootecnia sostenibile. *Ital. J. Agron.* 6(Suppl.2):e7.
- Reynolds, C.K., Mills, J.A.N., Crompton, L.A., Givens, D.I., Bannink, A., 2010. Ruminant nutrition regimes reduce greenhouse gas emissions in dairy cows. In: G.M. Crovetto (ed.) *Energy and protein metabolism and nutrition*. Wageningen Academic Publ., Wageningen, The Netherlands, pp 427-437.
- Russell, J.B., 1998. The importance of pH in the regulation of ruminal acetate to propionate ratio and methane production in

- vitro. *J. Dairy Sci.* 81:3222-3230.
- Singh, S., Kushwaha, B.P., Nag, S.K., Mishra, A.K., Bhattacharya, S., Gupta, P.K., Singh, A., 2011. In vitro methane emission from Indian dry roughages in relation to chemical composition. *Curr. Sci. India* 101:57-65.
- Spanghero, M., Berzaghi, P., Fortina, R., Masoero, F., Rapetti, L., Zanfi, C., Tassone, S., Gallo, A., Colombini, S., Ferlito, J.C., 2010. Technical note: Precision and accuracy of in vitro digestion of neutral detergent fiber and predicted net energy of lactation content of fibrous feeds. *J. Dairy Sci.* 93:4855-4859.
- Steinfeld, H., Gerber, P., Wassenaar, T., Castle, V., Rosales, M., de Haan, C. 2006. Livestock's long shadow: environmental issues and options. *FAO Publ.*, Roma, Italy.
- Tamburini, A., Colombini, S., Penati, C., Zucali, M., Roveda, P., Rapetti, L., Crovetto, G.M., 2010. Methane emission in livestock and diet characteristics. In: G.M. Crovetto (ed.) *Energy and protein metabolism and nutrition*. Wageningen Academic Publ., Wageningen, The Netherlands, pp 465-466.
- Tavendale, M.H., Meagher, L.P., Pacheco, D., Walker, N., Attwood, G.T., Sivakumaran, S., 2005. Methane production from in vitro rumen incubations with *Lotus pedunculatus* and *Medicago sativa*, and effects of extractable condensed tannin fractions on methanogenesis. *Anim. Feed Sci. Tech.* 123-124:403-419.
- Theodorou, M.K., Williams, B.A., Dhanoa, M.S., McAllan, A.B., France, J., 1994. A simple gas production method using a pressure transducer to determine the fermentation kinetics of ruminant feeds. *Anim. Feed Sci. Tech.* 48:185-197.
- Van Kessel, J.A.S., Russell, J.B., 1996. The effect of pH on ruminal methanogenesis. *FEMS Microbiol. Lett.* 20:205-210.
- Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods of dietary fiber, neutral detergent fiber and non-polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583-3597.

Non-commercial use only