Determination of enteric methane emissions of dairy cows fed with different diets and relationship with milk yield and ruminal function in order to improve advice for farmers

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Abstract

Methane from ruminal fermentation, termed enteric methane, contributes 40% of the total agricultural emissions (Gerber *et al.,* 2014). Mitigation of methane production could allow for a reduction in the impact of livestock on climate change and may improve the public perception towards this sector. Milk yield, methane emissions, carbon footprint and dietary costs were measured in experimental and commercial farms in different diet conditions: enriched fat diet (linseed or canola), high concentrate diet, high level of starch in diet or grazing. Individual milk samples were analysed monthly for milk quality and for methane emissions predicted by milk spectra analysis. The first results showed that methane emissions per kg of milk can vary from 11 to 20 g. Preliminary comparison between the diets demonstrated that feeding with grazed grass was beneficial in terms of feeding costs and environmental impact while methane emissions per kg milk were higher. Diets with low fibre content can have a beneficial impact to decrease methane emissions but could disturb ruminal function. These results will allow us to predict methane emissions and environmental impacts of milk production according to the diet composition, dietary costs, lactation stage and milk production. From these results, advice about feeding strategies could be given to reach the best compromise between environmental and economic objectives.

Keywords: animal nutrition, methane emissions, ruminal function, dairy sector, greenhouse gases

Introduction

Methane emissions from enteric fermentation of livestock are responsible for 40% of greenhouse gas (GHG) emissions from the agricultural sector (Gerber *et al.*, 2014). According to the literature, several strategies are available to mitigate these emissions (Knapp *et al*., 2014; Martin *et al*., 2010). One of them is the nutritional approach that aims to change ruminal fermentation patterns to decrease methane production. In this context, the first objective of the Life Dairyclim project was to optimize the feeding strategies during the winter (barn feeding) and the summer (grazing and supplementary feeding) and to evaluate the impact of these different diets on methane emissions and carbon footprint of milk. The tested feeding strategies were selected to be close to the usual rations given to dairy cows in Wallonia, Belgium. The zootechnical and economic aspects were also investigated.

Material and Methods

The trials were conducted during the Life Dairyclim project that began in October 2015. The experimental design was the same for all the trials i.e experimental groups receiving concentrate of different composition confronted with groups receiving control concentrate. During the first period of the project, 2015-2016, 2 different concentrate compositions were tested at the experimental farm of Sart Tilman (ULg) in Liège (Belgium) one being rich in starch (ST), the other one being rich in fat (FAT). In 2016-2017, trials were focused on concentrates rich in fat, composed of extruded linseed (Concentrate 1- ELS) and of extruded canola seed (Concentrate 2- CS). These trials were held at the Centre of Agronomic Technologies (CTA Belgium). The groups were balanced on the basis of days in milk (DIM) and lactation number (LN). During all the trials the cows received a diet composed of silages and by-products (total mixed ration = TMR), similar to the diets that Walloon farmers usually offer to their dairy herd (Table 1). Concentrates were provided at the feeding bin of the robot (ULg) or at the automatic concentrate feeder (CTA) as a complement to the TMR. The rations were calculated to ensure the same inputs in Control and Test groups and the amount of concentrates to be delivered was calculated on the basis of milk yield and days in milk (DIM). The ration differed by the amount of starch or fat. Nutritional composition of the diets offered during the different trials are presented on Table 2.

Table 1. Rations offered to the cows in 2015 and 2016

	2015-2016		2016-2017	
% DMI	Ration offered (ST vs control)	Ration offered (Fat vs control)	Ration offered (ELS vs control)	Ration offered (CS vs control)
Grass silage	29	28	22	27
Maize silage	24	22	26	29
Ensiled beet pulp	9	8	11	14
Brewers	5	5	-	-
Cereal crop silage	-		11	-
Hay	5	4	-	-
Straw	2	2	-	-
Concentrate rich in protein	9	9	9	7
Tested concentrate	17	22	21	21
Total DMI	19.5 kg	20.6 kg	24.6 kg	24.1 kg

Abbreviations: DMI: dry matter intake; ST: starch group; ELS:extruded linseed; CS: canola seed

Table 2. Nutritional composition of the different rations

g/kgDM	TMR + control	TMR + ST	TMR + control	TMR + Fat	TMR + control	TMR + ELS	TMR + control	TMR + CS
DM	430	430	437	437	360	360	360	360
CP	149	145	157	155	158	158	149	148
Starch	108	132	112	124	139	151	142	157
Fat	37	37	37	43	36	48	34	47
NDF	352	395	324	386	410	391	413	392

Abbreviations: DM: dry matter; TMR: total mixed ration; ST: starch; ELS: extruded linseed; CS: canola seed; CP: crude protein

Trials were performed also on grazing cows. In 2017, 2 contrasting rations were tested regarding enteric methane emissions and carbon footprint of produced milk during 72 d. Therefore, cows receiving a dry ration (DR group) were compared with those whose ration was composed of grazed grass (G group). The DR group ration was composed of 12.2 kg DM concentrates, 1.7 kg DM straw, 0.7 kg DM molasses and 3.6 kg DM alfalfa pellets while the G group grazed day and night. Concentrates (3.5 kg, 16% CP) were allocated in both groups to allow passage to the automatic concentrate feeder. In 2018, a gradient of grazed grass was tested within 3 groups: one receiving 100% grazed grass (group 100%), the second 50% (group 50%) and the third one 0% (group 0%) during 45 d. Concentrates (16% CP) were supplied at the automatic concentrate feeder (2 kg.cow^{-1}d^{-1}). The TMR of Group 0 and 50 % were based on forages (88%). The DMI (dry matter intake) of each group was targeted at 20 kg DM with an energy input of 20 kVEM. Methane emissions were calculated by 2 methods: the measurements of the CH_4 emitted in breath samples using the Guardian® inserted in the feeding bin of the robot (Sart Tilman) or in the automatic concentrate feeder (CTA) and by predictions based on analysis of the milk spectra (Vanlierde *et al*., 2016). The results obtained with the Guardian® are not presented in this publication.

Milk yield and concentrate consumption were recorded on a daily basis.

Carbon footprint of diets was calculated using the LCA methodology with Feedprint® model tool (Vellinga *et al*., 2014).

Feeding costs were calculated on the basis of purchase invoices. The silage production costs were estimated by the software “Dégâts du gibier” developed by Fourrages Mieux ASBL. Costs of grazed grass took into consideration the grass yield and inputs to the pastures.

At grazing, grass availability was assessed on the basis of grass height measurements.

Statistical analysis

Data were at first analysed by descriptive statistic methods (proc means and proc univariate – SAS 9.3). Proc mixed modelling was used to take into account repeated measurements (repeated days/subject animal) and a covariance analysis type AR(1) in 2015-2016 and type cs in 2016-2017. The models the most adapted to the trials were chosen on the basis of AIC criteria. These procedures were repeated for each trial period: Trial with concentrate rich in starch and concentrate rich in fat in 2015-2016 and in 2016-2017 for the trial ELS, trial CS and grass experiments in 2017 and 2018.

Results

The results of the different trials are presented in Table 3, 4, 5 and 6. In 2015-2016, no statistical difference was observed. In 2016-2017, methane emissions (g.cow^{-1}.d^{-1}) were decreased in ELS and CS compared with control groups. The decrease in methane g.kg milk^{-1} reached more than 10% in ELS group. During the summer trials, different results were observed. The comparison between the dry ration and the 100 % grazing demonstrated lower methane emissions with the DR whatever the chosen unit. In trials held in 2018, lower daily methane emissions per cow were observed in the group 0%. The methane production per kg milk and per kg ECM showed no difference between the groups.

Table 3. Results of Trial Starch (ST) and Fat (FAT) conducted in 2015-2016.

	Control	ST	Sig	Control	FAT	Sig
MY (kg cow^{-1}.d^{-1})	28.3 ± 1.5	24.8 ± 1.6	***	29.3 ± 1.2	30.4 ± 1.2	ns
% Fat	3.6 ± 0.1	3.7 ± 0.1	ns	3.8 ± 0.1	3.7 ± 0.1	ns
% Protein	3.4 ± 0.1	3.4 ± 0.1	ns	3.3 ± 0.0	3.3 ± 0.0	ns
ECM (kg cow^{-1}.d^{-1})	26.9 ± 1.4	23.7 ± 1.4	***	28.6 ± 1.2	29.4 ± 1.2	ns
CH4 (g cow^{-1}.d^{-1})	416 ± 10	424 ± 10	ns	465 ± 7	459 ± 7	ns
CH4 (g kg^{-1}milk)	16.1 ± 1.1	19.3 ± 1.1	**	17.0 ± 0.8	16.4 ± 0.8	ns
CH4 (g kg^{-1}ECM)	16.7 ± 1.0	19.9 ± 1.0	*	17.4 ± 0.8	16.9 ± 0.8	ns
Concentrate intake (kgDM cow^{-1}.d^{-1})	3.4 ± 1.7	3.4 ± 1.7	ns	5.3 ± 1.7	5.1 ± 1.7	ns

Abbreviations: MY: milk yield; ECM: energy corrected milk. Values are LSmeans ± SE. The statistics results show the group effect. ns: not significant; *: $p < 0.05$; **: < 0.01; ***: $p < 0.001$

Table 4. Results of Trial with extruded linseed (ELS) and canola seed (CS) conducted in 2016-2017.

	Control	ELS	Sig	Control	CS	Sig

MY (kg cow^{-1}.d^{-1})	34.4 ± 0.5	36.6 ± 0.5	***	34.8 ± 0.7	36.3 ± 0.7	trend
% Fat	4.0 ± 0.1	3.8 ± 0.1	*	3.8 ± 0.1	3.8 ± 0.1	ns
% Protein	3.7 ± 0.0	3.2 ± 0.0	***	3.4 ± 0.1	3.3 ± 0.1	ns
ECM (kg cow^{-1}.d^{-1})	34.4 ± 0.5	35.3 ± 0.5	ns	34.7 ± 0.8	34.9 ± 0.8	ns
CH4 (kg cow^{-1}.d^{-1})	485 ± 4	462 ± 4	***	475 ± 7	469 ± 7	ns
CH4 milk (g kg^{-1}milk)	14.6 ± 0.2	12.9 ± 0.2	***	14.1 ± 0.4	13.1 ± 0.4	*
CH4 ECM (g kg^{-1}ECM)	14.4 ± 0.2	13.4 ± 0.2	***	14.3 ± 0.4	13.9 ± 0.4	ns
Concentrate intake (kgDM cow^{-1}.d^{-1})	5.0 ± 0.2	4.6 ± 0.2	***	4.8 ± 0.2	4.8 ± 0.2	ns

Values are LSmeans ± SE. Abbreviations: MY: milk yield; ECM: energy corrected milk. The statistics results indicate the group effect. ns: not significant; trend: 0.1; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$

Table 5. Results of Trial DR. Group DR: received a dry ration and Group G was 100% grazing.

	Dry Ration	Grazing	Sig
MY (kg.cow^{-1}.d^{-1})	36.3 ± 1.4	26.1 ± 1.4	***
% Fat	3.0 ± 0.1	3.5 ± 0.1	***
% Protein	3.1 ± 0.0	3.0 ± 0.0	ns
ECM (kg.cow^{-1}.d^{-1})	31.3 ± 1.2	23.9± 1.2	***
CH4 (kg.cow^{-1}.d^{-1})	435 ± 10	451 ± 10	ns
CH4 (g.kg^{-1}milk)	12.3 ± 0.5	18.1 ± 0.5	***
CH4 ECM (g.kg^{-1}ECM)	14.2 ± 1.0	19.8 ± 1.0	***

Values are LSmeans ± SE. Statistical values indicate the group effect.. ns: not significant; trend: 0.1; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$

Table 6. Results of the Trial 0%. 50%. 100% grass.

	0% grass	50% grass	100% grass	Sig
MY (kg cow^{-1} d^{-1})	28.5 ± 1.3	27.2 ± 1.2	25.2 ± 1.3	ns
ECM (kg cow^{-1} d^{-1})	27.5 ± 1.5	25.2 ± 1.4	24.2 ± 1.5	ns

% Fat	3.7 ± 0.2	3.8 ± 0.2	3.6 ± 0.2	ns
% Protein	3.2 ± 0.1	3.2 ± 0.1	3.1 ±0.1	ns
CH4 (kg cow^{-1} d^{-1})	475 ± 9^{a}	440 ± 9^{b}	430 ± 9^{b}	*
CH4 (g kg^{-1}milk)	17.7 ± 1.1	17.3 ± 1.1	17.9 ± 1.1	ns
CH4 ECM (g.kg^{-1}ECM)	18.3 ± 0.9	17.9 ± 0.9	19.3 ± 0.9	ns

Values are LSmeans ± SE; ns: not significant; *: $p < 0.05$.

Feeding costs

The impact of the different diets on feeding costs was evaluated. Independently from the study’s year, full grazing diets were the cheapest per cow per day or per 100 kg milk produced (Table 7).

Table 7. Feeding costs of all the studied diets. Costs are expressed in € per cow and per day or per 100 kg milk produced.

		Feeding costs		
		Per cow.d €	Per 100 kg milk €	Milk yield (kg cow^{-1}.d^{-1})
2015-2016	Control feed	3.98	14.0	28.3
	ST	4.03	16.2	24.8
	FAT	4.35	14.3	30.4
2016-2017	Control feed	4.22	11.8	34.6
	ELS	4.35	12.2	36.8
	Control feed	4.12	12.1	33.9
	CS	4.31	11.9	36.0
	DR	5.93	16.5	36.3
	G	1.98	8.0	26.1
2018	0%	4.73	16.6	28.5
	50%	3.36	12.3	27.2
	100%	2.19	8.7	25.2

Climate impact of tested diet

The climate impact of each diet was evaluated by checking the carbon footprint total of each feedstuff. Values of silages and grazed grass were adapted in relationship with their DM. Values were put in correlation with the evaluated control diet. Values are expressed per kg milk and kg ECM.

Climate impact (g eqCO2) per kg milk and per kg ECM was estimated for all the tested diets.

The CF of tested compounds were generally higher than control ones. The diet incorporating grazed grass had generally a lower CF than the control ones (Table 8).

Table 8. Climate impact (g eqCO2) per kg milk and per kg ECM for all the tested diets.

Year of trial	Tested diet	g eq CO2/kg milk	g eq CO2/kg ECM
2015-2016	Control	269	283
	ST	308	323
	Control	234	274
	Fat	256	274
2016-2017	Control	308	312
	ELS	315	318
	Control	297	307
	CS	311	323
	DR	498	576
	G	356	390
2018	0%	363	377
	50%	339	362
	100%	322	353

Discussion

Diminution in enteric methane emissions were noted when compounds rich in fat (Fat; ELS; CS) were added to the total mixed ration. It must to be highlighted that a substantial amount has to be given to reach a noticeable effect. The use of these components is to be limited to early calving cows. The higher the milk yield, the higher enteric methane reduction. At grazing, no effect on methane emissions per cow per day was observed possibly because of high grass quality. Conversely, the decrease in milk yield observed for full grazing diets induced an increase in methane emissions per kg produced in 2017. This observation was not confirmed in 2018. The carbon footprint in relationship to the provided diet took into consideration only the climate impact and not other environmental indicators like biodiversity index or land use change. Values are dependent on forage quality. For example, the dry matter of silages has a huge impact on figures. Use of each tested concentrate increased the carbon footprint of the diet while grazing decreased it. However the impact was moderate. The incorporation of concentrate rich in fat induced an increase in production costs that was partly attenuated by the higher milk production. Grazing was the most beneficial in terms of feeding costs.

Conclusion

This compilation of trials' results over several years highlights the difficulty to get a unique overview of the effects of introducing new compounds in cows' diets. Some negative effects could counteract the positive effects observed when a change is made. Advisors should keep in mind this difficulty.

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