doi: 10.15174/au.2018.1766 | ISSN online: 2007-9621

Acta Universitaria
Multidisciplinary Scientific Journal

Animal nutrition strategies to reduce greenhouse gas emissions in dairy cattle

Estrategias de nutrición animal para reducir emisiones de gases de efecto invernadero en ganado lechero

Recibido: 28 de enero del 2017
Aceptado: 20 de abril del 2018
Publicado: 6 de noviembre del 2018

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Cómo citar:

Rendón-Huerta, J. A., Pinos-Rodríguez, J. M., & Kebreab, E. (2018). Animal nutrition strategies to reduce greenhouse gas emissions in dairy cattle. Acta Universitaria, 28(5), 34-41. doi: 10.15174/au.2018.1766

Keywords:
Nitrogen excretion; feeding manipulation; methane; nitrous oxide; milk.

Palabras Clave:
Excreción de nitrógeno; manipulación de la alimentación; metano; óxido nitroso; leche.

ABSTRACT

The objective of this study was to analyze different animal nutrition strategies from published papers to reduce greenhouse gas (GHG) emissions, particularly methane (CH_4) and nitrous oxide (N_2O) in dairy cattle. Ration data used (*n* = 32 diets) was obtained from 15 published papers selected according to differences between forage:concentrate ratio and crude protein (CP) content. An empirical model was used to estimate enteric methane emissions based on fiber and CP content in the diets. The N_2O emission was calculated according to Intergovernmental Panel of Climate Change (IPCC) recommendations. Differences between CH_4 and N_2O affected by FC or CP content were analyzed through a variance analysis. Furthermore, a correlation analysis was carried out to compare CP content and nitrogen excretion in feces, urine and milk. Estimations of enteric CH_4 were not significantly different between diets with various forage content levels. Diets with high concentrate content had lower GHG intensity. Nitrogen excretion in feces and urine increased linearly as dietary protein level was increased from the lowest to the highest concentrations, but conversion of nitrogen intake to nitrogen excreted in milk was not affected by increasing dietary protein. In conclusion, dietary manipulation could decrease GHG emissions by unit of produced milk.

RESUMEN

El objetivo de este estudio fue analizar diferentes estrategias de alimentación animal de diferentes artículos publicados para disminuir las emisiones de gases de efecto invernadero (GEI), en particular metano y óxido nitroso, en ganado lechero. Datos de dietas usados (32 dietas) fueron obtenidos de 15 estudios publicados y seleccionados de acuerdo a diferencias entre la proporción de forraje: concentrado y el contenido de proteína cruda (PC). Se utilizó un modelo empírico para estimar las emisiones de metano entérico basado en el contenido de fibra y PC en las dietas. Las emisiones de N_2O fueron calculadas de acuerdo a las recomendaciones del Grupo Intergubernamental de Expertos sobre el Cambio Climático (IPCC, por sus siglas en inglés). Diferencias entre CH_4 y N_2O afectados por el contenido de Forraje y PC, fueron analizados mediante un análisis de varianza. Además, se realizó un análisis de correlación para comparar el contenido de PC y la excreción de nitrógeno en el estiércol, la orina y la leche. No se presentaron diferencias significativas en estimaciones de CH_4 de entérico entre dietas con distintos contenidos de forraje. Las dietas con mayor contenido de concentrado presentaron las menores intensidades de GEI. La excreción de nitrógeno en el estiércol y la orina se incrementó linealmente al aumentar el contenido de proteína, desde las concentraciones más bajas a las más altas, pero la conversión de nitrógeno consumido a nitrógeno en leche no se vio afectado por incrementos de proteína en la dieta. En conclusión, la manipulación de las raciones podría reducir las emisiones de GEI por unidad de producción de leche.

INTRODUCTION

Global human population is constantly increasing, which drives food demand, especially animal-based products such as meat and milk (Steinfeld *et al.*, 2006). To meet the demand, increased intensification of agricultural practices was necessary during the last 60 years (Capper, Cady & Bauman, 2009). Dairy production systems, as an important component of the livestock sector, produced 600 million tons of milk in 2010 (Food and Agriculture Organization of the United Nations [Faostat], 2012); 67% more than that produced in 1970. It is recognized that animal production systems, such as dairying, are important and complex sources of greenhouse gases (GHG), particularly methane (CH_4) and nitrous oxide (N_2O) (Steinfeld *et al.*, 2006). CO_2, CH_4, and N_2O absorb heat from infrared rays coming from the sun and contribute to climate change; with a warming potential equivalent to 1, 28 and 265 times that of CO_2 over a 100-year period, respectively (Intergovernmental Panel of Climate Change [IPCC], 2013). National Aeronautics and Space Administration (NASA, 2012) reported a global surface air temperature change of about 0.6 °C in the last century. Globally, fossil combustion is responsible for the majority of GHG emissions. Approximately 14% of the anthropogenic GHG emissions are attributed to agricultural activities (crops and livestock) (IPCC, 2007). Livestock production systems contribute about 42% of total GHG production from agriculture, 28% of which is associated with direct emissions of enteric fermentation (CH_4) and 14% (CH_4 and N_2O) from indirect emissions related to manure handling, storage, and their use as fertilizer (Mosier *et al.*, 1998). Dietary carbohydrates such as cellulose, hemicellulose, pectin, starch and soluble sugars are the main sources of energy and are degraded by microorganisms into the rumen to hexoses and pentoses before being fermented to volatile fatty acids (acetate, propionate and butyrate), hydrogen (H_2) and CO_2. An excess of H_2 is produced when diets with high forage content are fermented. Microorganisms derive glucose from structural carbohydrates (cellulose and hemicellulose), through the Embden-Meyerhof and pyruvate-formate lyase pathways which produce formate and acetyl-coenzime A (CoA). Formate is converted to CO_2 and H_2, and CoA is transformed to acetate [1] or butyrate via β-oxidation pathway [2]. For example, diets with forage:concentrate ratio equal to 75:25 generally produce high acetate:propionate molar ratio (68:18) (Fahey & Berger, 1988). In contrast, diets with higher concentrate content (40:60), present high fermentable carbohydrates (oligosaccharides, pectin and starch) that utilize H_2 for propionate synthesis [3] through succinate and acrylate pathways (Fahey & Berger, 1988; Van Soest, 1982).

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2C_2H_4O_2 \text{ (acetate)} + 2CO_2 + 8H \qquad [1]$$

$$C_6H_{12}O_6 \rightarrow C_4H_8O_2 \text{ (butyrate)} + 2CO_2 + 4H \qquad [2]$$

$$C_6H_{12}O_6 + 4H \rightarrow 2C_3H_6O_2 \text{ (propionate)} + 2H_2O \qquad [3]$$

$$CO_2 + 8H \rightarrow CH_4 + 2H_2O \qquad [4]$$

Once H_2 is generated, it is the main substrate for microbes called methanogenic archaea that produce CH_4 [4] as an end-product of methanogenic microbes' metabolism, which also help the rumen to maintain a stable environment (Moss, Jouany & Newbold, 2000). Most of CH_4 (87%) is produced in the rumen; the rest (13%) is produced in the large intestine. Enteric CH_4 is primarily emitted from the animal by eructation (Murray, Bryant & Leng, 1976). Kebreab, Dijkstra, Bannink & France (2009) argued that methane emission by ruminants is not only an environmental concern but also a loss of productivity because CH_4 represents a loss of carbon, and therefore an unproductive use of dietary energy that could be around 2% to 12% of gross energy intake (Johnson & Johnson, 1995).

Dairy farm intensification has been accompanied by an increase in N surplus through crude protein (CP) (Dijkstra *et al.*, 2010). Dairy producers often feed high CP diets to ensure a sufficient supply of the metabolizable protein required for maximal milk and protein production (Colmenero & Broderick, 2006). Ruminants fed high protein content (dietary protein and non-protein nitrogen) degrade the nitrogen source in the rumen by ruminal microbes to peptides, amino acids (AA), and eventually to ammonia (NH_3), that can be flushed through the gastrointestinal system (omasum-abomasum-small intestine) to be digested (Owens & Zinn, 1988), and undegradable proteins are excreted. Ammonia is either absorbed directly through the rumen wall into blood or enters the small intestine (SI) where it is absorbed into the portal vein, then taken by the liver for urea synthesis. Excess urea is recycled back to the digestive tract, entering the rumen through saliva or by diffusion through the ruminal wall where it is hydrolyzed to ammonia and CO_2 by microbial urease. Part of it is excreted by the kidneys via urine (figure 1), with important implications, once in contact with feces, it is more susceptible to leaching and volatile losses, contributing to NH_3 and N_2O emissions (Castillo, Kebreab Beever & France, 2000; Hristov *et al.*, 2010). The N_2O is released during microbial transformation of N in the soil or in manure. For example, nitrification of NH_4^+ into NO_3^- and incomplete denitrification of NO_3^- into N_2 (Oenema *et al.*, 2005). The IPCC (2006) reported N_2O emission factor of 1g per kg N in anaerobic slurries in lagoons. Globally, dairy cattle produce 15.8% of N_2O into the livestock sector and confirmed dairy systems are responsible for 4.3% of the emissions (Oenema *et al.*, 2005).

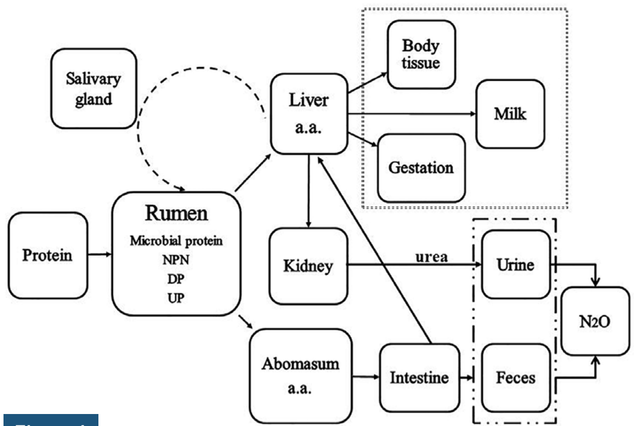

Figure 1

Schematic representation of protein metabolism in the lactating cow (-------) N recycled, (·······) N absorption in milk and body weight gain, and (– ·· – ·· –) N excretion. Non-Protein Nitrogen (NPN), Degradable Protein (DP), Undegradable Protein (UP) (Owens & Zinn, 1988).
Source: Author's own elaboration.

Until now, dairy scientists have made enormous strides in increasing milk yields in cows. This has been done through better nutrition, animal health, improved genetics, increased milking frequency, and photoperiod manipulation (Connor, Hutchison, Olson & Norman, 2012), but little attention has been given to the outputs, such as nutrient excretion in feces and urine (nitrogen and phosphorus), or loss of energy (CH_4). Nowadays one of the most important concerns in animal science is to decrease the environmental impact of the dairy industry by reducing waste outputs and improving the efficiency of production in dairy cows. Therefore, the main objective of this work was to analyze different animal feeding strategies to reduce GHG emissions in dairy cattle.

METHODS

Data Sources

For this research, the data consisted of 32 diets obtained from Agle *et al.* (2010); Aguerre, Wattiaux, Powell, Broderick & Arndt (2011); Arriaga, Pinto, Calsamiglia & Merino (2009); Brito & Broderick (2006); Burkholder, Guyton, McKinney & Knowlton (2004); Colmenero & Broderick (2006); Davidson *et al.* (2003); Gehman & Kononoff (2010); Groof & Wu (2005); Ipharraguerre & Clark (2005); Knowlton, Wilkerson, Casper & Mertens (2010); Martin, Rouel, Jouany, Doreau & Chilliard (2008); Rius, McGilliard, Umberger & Hanigan (2010); van Zijderveld *et al.* (2011); Weiss *et al.* (2009). All experiments in these researches used Holstein Friesian cows. Researches were selected according to differences between forage:concentrate ratio and CP content; the diets were then divided by forage content (FC): low FC < 45%, medium FC 46% to 55% and high FC > 56%. Additionally, diets were divided by CP content: low CP with less than 15% CP, medium CP between 15.1% and 16.5% CP, and diets with more than 16.6% CP. The main reason to classify the information was that it has been documented that by manipulating the diet, emissions of greenhouse gases could be altered, in some cases one of them could be reduced, while in some others it might be increased, methane and nitrous oxide mainly.

Greenhouse gas estimation

Nitrogen excreted in manure (feces and urine) was used to estimate nitrous oxide (N_2O), as 0.001 kg of N_2O per kg of N excreted in manure (feces and urine, data obtained from the published papers), assuming that manure is handled in slurry lagoons (IPCC, 2006). Methane emissions were estimated with the empirical model of Moe & Tyrrell (1979) that takes into consideration the relationship between feed intake and diet composition to estimate methane emissions. The model is described as follows:

$$\text{Methane (MJ/d)} = 3.38 + 0.51\ \text{NFC (kg/d)} + 2.14\ \text{HC (kg/d)} + 2.65\ \text{C (kg/d)}$$

where NFC is non-fiber carbohydrate, HC is hemicellulose and C is cellulose.

Hemicellulose was calculated as: HC = FDN – FDA; Cellulose was calculated as: C = FDA – lignin; lignin values were calculated with the National Resourse Council (NRC, 2001). Non-fiber carbohydrate was determined as: NFC kg/d = 100 – (Crude Protein (kg/d) + Fat (kg/d) + Ash (kg/d) + Neutral Detergent Fiber (kg/d)).

Methane estimations from manure were not estimated due to lack of information.

The global warming potential (GWP) of CH_4 and N_2O were 28 and 265, respectively, expressed as CO_2 equivalent, based on IPCC (2007) recommendations.

Data Analysis

To compare nitrogen efficiency considered as the CP content (%) in diets, compared to the nitrogen excretion (faeces, urine and milk, g/d) data, a correlation analysis was run in R programming language (R Development Core Team, 2012). To assess the differences between GHG affected by FC or CP content, an analysis of variance (One-way analysis) and the Tukey-Kramer test were carried out for post-hoc analysis, at a significance level of $p < 0.05$.

RESULTS AND DISCUSSION

Our analysis was focused on GHG emissions at the animal level, i.e., CH_4 and N_2O emissions through nutrient digestion taken from different diets in some researches; the study does not represent the whole farm analysis. Greenhouse gas emissions affected by FC in the diet are presented in table 1.

There were no differences in CP, % and dry matter intake (DMI) between diets; however, FC varied among diets ($p < 0.0001$), with the highest FC being 61.5%. Even if differences in CP content were not significant, diets with low FC content (45%) had the highest CP content (17.4%), which is in excess the NRC (2001) recommendations that should be around 16% CP content, the main implication is that this excess of nitrogen represents a cost to farmers. Cows fed diets with < 45% FC had the highest milk yield (35.5 kg/d) and feed efficiency of 1.45 kg Milk/kg DMI (table 1) and were statistically different from rations with more than 60% FC ($p < 0.0001$). There was no difference in N intake, but the highest value was observed in rations with less than 45% forage (680 g cow/d). Nitrogen excretion in feces and milk showed statistical differences ($p < 0.001$ and $p < 0.01$, respectively); greater N excretions values in feces and milk were found with diets with less than 45% FC (279 g/d and 170 g/d, respectively). Differences in urine N excretions were not significant. Efficiency of N utilization was similar between the three FC diets. On the other hand, GHG emissions were not significant in relation to N_2O. A decrease in N_2O emissions was estimated with rations with equal or more than 46% forage (0.42 g/d). Estimations of enteric CH_4/cow were not significantly different between diets with various FC levels. However, there was a difference in GHG emission intensity, i.e. emissions per unit of milk ($p < 0.0001$). Diets with high concentrate content had lower GHG intensity. Even if the statistical analysis of enteric CH_4 emissions across studies did not show differences, it is well documented that an increase in digestibility reduces rumen nutrient digestion and CH_4 production (Yan *et al.*, 2010), which was also observed in diets with less than 45% forage. Regarding efficiency of emissions of CH_4 per unit of milk, our analysis agrees with that reported by Aguerre *et al.* (2011), who found that CH_4 emissions per unit of milk increased when FC in the diet increases. This is due to an increase in Neutral Detergent Fiber (NDF) intake and a decrease in milk yield. On the other hand, van Zijderveld *et al.* (2011) reported that another strategy to reduce enteric CH_4 emissions in cows fed high FC was the addition of nitrate to corn silage-based diets, but this strategy does not affect diet digestibility and milk production.

Table 1 GHG emissions comparison by forage content (FC) in diets

	FC > 56 %		FC 46-55 %		FC < 45 %		*p* value
CP%	15.9	±1.9	16.7	±1.1	17.4	±1.6	0.136
BW	637	±37	627	±38	615	±43	0.531
DMI, $kg \cdot d^{-1}$	23.2	±2.1	23.1	±1.2	24.4	±0.9	0.108
Forage:concentrate ratio	61:39:00	±2.4	50:50:00	±1.4	40:60	±5.1	0.001
ADF, %	19.6	±1.9	19.3	±6.7	21.5	±3.2	0.223
NDF, %	36.3	±3.4	31.8	±9.4	31.4	±6.5	0.136
Milk yield, $kg \cdot d^{-1}$	29.8^b	±2.7	35.0^a	±3.9	35.5^a	±2.5	***
Feed efficiency, kg Milk/ kg DMI	1.29^b	±0.5	1.54^a	±0.2	1.43^a	±0.1	***
N intake, $g \cdot d^{-1}$	611	±92	610	±65	680	±75	0.083
Fecal N, $g \cdot d^{-1}$	229b	±55	221^b	±30	279^a	±34	**
Urine N, $g \cdot d^{-1}$	203	±85	211	±44	240	±47	0.384
Manure N, $g \cdot d^{-1}$	433	±128	419	±85	515	±70	0.068
Milk N, $g \cdot d^{-1}$	150^b	±21	167^a	±17	170^a	±14	*
Milk $N \cdot N^{-1}$ intake, %	25.1	±2.8	27.8	±3.9	25.1	±2.6	0.095
GHG emissions							
N_2O, $g \cdot d^{-1}$	0.43^b	±0.1	0.42^b	±0.0	0.51^a	±0.0	0.068
CH_4, $g \cdot d^{-1}$	426	±24	408	±56	396	±15	0.274
CH_4, $g \cdot kg^{-1}$ DMI	18.5	±2.4	17.7	±3.0	16.2	±0.3	0.122
CH_4, $g \cdot kg^{-1}$ Milk	14.4^a	±1.7	11.6^b	±1.6	11.1^b	±0.6	***
CO_2 eq, $kg \cdot d^{-1}$	12,7	±0.6	11.5	±1.4	11.2	±0.3	0.289
CO_2 eq, $kg \cdot kg^{-1}$ DMI	519	±61	499	±75	460	±7.6	0.128
CO_2 eq, $kg \cdot kg^{-1}$ Milk	404^a	±43	329^b	±41	316^b	±15	***

*** = 0; ** = 0.001; * = 0.01. Treatments with different letter are different by column. Dry Matter Intake (DMI), Body Weight (BW).
Source: Author's own elaboration.

Results of GHG emissions affected by CP content in diets are shown in table 2. When data of CP content was combined across studies, CP excretion in feces (SEM = 3.38; p < 0.0001) and urine (SEM = 4.11; p < 0.0001) increased linearly as dietary protein was increased from the lowest to the highest concentrations (figure 2).

Conversion of nitrogen intake to nitrogen excreted in milk was not affected by increasing dietary protein (Standard Error of the Mean [SEM] = 2.04; p > 0.134). Once diets from all studies were divided according to CP content, a statistical difference was observed (p < 0.001) in nitrogen intake, nitrogen excretion in feces, urine and manure (p < 0.001), the values were higher in diets with high CP (CP > 16.6%), 697, 273, 247 and 517 g/d, respectively; but differences of CP in milk were not significant (table 2).

Thus, there were differences in efficiency of nitrogen utilization (p < 0.001); higher nitrogen efficiency (29.2%) was more relevant in diets with low CP (CP < 15%), but as a CP increased, N utilization decreased (24.3%). Rius *et al.* (2010) reported that efficiency of N utilization is higher when feeding the combination of high energy and low CP in the diet. Our results are consistent with other studies that report N excretion. For example, Agle *et al.* (2010) and Groof & Wu (2005) and reported that as N intake increases, N in manure (feces and urine) increases, resulting in a decrease of N utilization and the accumulation of ammonia. The results of this research confirm that urinary N excretion increased more rapidly than fecal N did as dietary protein was increased (60% and 41%, respectively), and these results are consistent with those by Groof & Wu (2005). These observations suggest that an excess of N requirement not only represents an increase of N excretion and economic loss for producers, but it also represents a negative impact in surface and groundwater and increase the risk of N converted to N_2O, because ammonia in urine is more labile than ammonia in feces (Dijkstra *et al.*, 2010; Varel, Nienaber & Freetly, 1999).

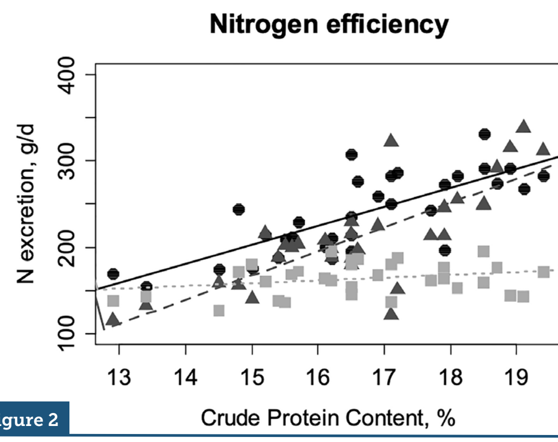

Figure 2

Nitrogen excretion related with percentage of crude protein in the diet, (●) feces, (▲) urine, and (■) milk..
Source: Author's own elaboration.

Table 2 GHG emissions comparison by crude protein (CP) content

	LCP< 15 %		MCP 15.1-16.5 %		HCP > 16.6 %		*p* value
CP%	14.2c	±1.0	16.1b	±0.4	18.1a	±0.9	***
Forage:concentrate ratio	49:51:00	±9.2	51:49:00	±7.7	49:51:00	±5.5	0.999
BW	644	±32	624	±41	621	±46	0.486
DMI, $kg{\cdot}d^{-1}$	23	±0.9	22.8	±1.2	24.3	±1.2	0.042
ADF, %	24	±7.4	20.6	±6.0	21.2	±4.3	0.209
NDF, %	36.1	±9.0	34.8	±7.6	32.7	±7.5	0.524
Milk yield, $kg{\cdot}d^{-1}$	32.3	±2.9	34.2	±4.6	34.1	±2.4	0.627
Feed efficiency, Milk·DMI	1.4	±0.1	1.5	±0.2	1.41	±0.1	0.33
N intake, $g{\cdot}d^{-1}$	525[c]	±43	592[b]	±43	697[a]	±51	***
Fecal N, $g{\cdot}d^{-1}$	189	±36	217[b]	±37	273[a]	±35	***
Urine N, $g{\cdot}d^{-1}$	153[c]	±38	200[b]	±17	247[a]	±49	***
Manure N, $g{\cdot}d^{-1}$	344[b]	±67	400[b]	±69	517[a]	±72	***
Milk N, $g{\cdot}d^{-1}$	153	±18	164	±20	167	±15	0.324
Milk $N{\cdot}N^{-1}$ intake, %	29.2[a]	±2.7	27.8[b]	±3.5	24.3c	±2.7	***
GHG emissions							
N_2O, $g{\cdot}d^{-1}$	0.34[c]	±0.0	0.40[b]	±0.0	0.52a	±0.2	***
CH_4, $g{\cdot}d^{-1}$	400	±9.1	391	±21	403	±18	0.252
CH_4, $g{\cdot}kg^{-1}$ DMI	17.5	±1.8	17.1	±1.0	16.6	±0.6	0.17
CH_4, $g{\cdot}kg^{-1}$ Milk	12.6	±2.0	11.6	±1.8	11.9	±1.1	0.487
CO_2 eq, $kg{\cdot}d^{-1}$	11.3	±2.4	11	±5.4	11.4	±4.6	0.19
CO_2 eq, $kg{\cdot}kg^{-1}$ DMI	491	±44	485	±25	470	±15	0.224
CO_2 eq, $kg{\cdot}kg^{-1}$ Milk	350	±52	323	±47	335	±26	0.511

*** = 0; ** = 0.001; * = 0.01. Treatments with different letter are different by column. Dry Matter Intake (DMI), Body Weight (BW).
Source: Author's own elaboration.

GHG estimations were affected by CP % content just for N_2O estimations (P < 0.001), higher N_2O values were found in diets with high CP % content (0.52, g/d), this was because N_2O is related to N excretion in manure in the nitrification and denitrification processes. Oenema *et al.* (2005), mention that improving N use efficiency is the most feasible option for N_2O mitigation. Differences between CH_4 and CO_2 equivalent estimations affected by CP % were not found. This could be because FC content was similar between groups. As a result, carbon footprint per unit of product or per kg of DMI was not affected because there were not differences in milk yield and DMI per cow. Hristov *et al.* (2012) reported that changing diet composition across one year according to the cow production status and energy requirements, some GHG emissions can be affected through reducing dietary CP concentration on commercial dairy farms without affecting milk yield and composition in dairy cows. The same authors mentioned that feeding a diet with 15.4% CP content showed a reduction of 23% in NH_3 emissions in manure, but the diet does not decrease CH_4 emissions, which agreed with the results obtained in our study. Kebreab *et al.* (2009) agreed that reducing dietary protein concentration, similar protein degradability to the microbial requirement and increasing the animal energy status will reduce the output of N in manure. Burkholder *et al.* (2004) reported that altering dietary starch source using steam flaked corn improved nutrient digestibility and reduced DMI, N intake and N excretion that could reduce ammonia losses from manure. The same authors reported that despite a reduction in DMI, lactation performance was not affected. Other strategies reported by Brito & Broderick (2006) showed that with diets of 51% FC (24 alfalfa silage: 27 corn silage) and 16% CP content, N excretion per unit of product was reduced. On the other hand, they mentioned that by reducing the percent of alfalfa in the diet, urinary urea and N excretion decreased, however, animal performance (milk yield, milk fat content and fiber digestibility) decreased as well. Capper *et al.* (2009) pointed out that while improving animal productivity results in increased GHG emissions per animal, the high milk response rate results in a trend of decreasing net emissions per unit of output. Finally, the diets with better nutritional strategies to reduce GHG in cows producing (36.5 kg milk/d, ±1.94) and emitting 277 g CO_2 eq/kg milk (±12.5) were those reported by Brito & Broderick (2006); Colmenero & Broderick (2006); Davidson *et al.* (2003); Groof & Wu (2005); Ipharraguerre & Clark (2005); Knowlton *et al.* (2010), Rius *et al.* (2010) and Weiss *et al.* (2009) and that in general contain the following characteristics: FC (45%, ±6.3) and CP % (16.8, ±1.3)

In conclusion, dietary manipulation can help decrease two of the most important gases produced in confined dairy systems. Studies demonstrated that cows of 625 kg, producing more than 35 kg milk/d and fed diets with forage:concentrate ratio equivalent to 50:50 and 16% CP emitted less CH_4 per unit of product and improved nitrogen utilization (11.3%), in contrast to those diets with high FC (FC > 56%) and low CP content (CP < 15.9). Dietary manipulation can also decrease N_2O production (21.4%), in contrast to diets with low FC (FC < 45%) and, at the same time, reduce carbon footprint by unit of milk output, and it could have potential economic benefits as well.

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