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Looking for high-production and sustainable diets for lactating cows: A survey in Italy

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ABSTRACT

The aim of the present study was to evaluate, through a survey conducted on commercial farms, the global warming potential (GWP) of different lactating cow total mixed rations (TMR) and to identify the best dietary strategies to increase feed efficiency (FE) and reduce enteric CH_4 emission. A total of 171 dairy herds were selected: data about dry matter intake (DMI), lactating cow TMR composition, and milk production and composition were provided by farmers. Diet GWP (kg of CO_2 equivalents; CO_2eq) was calculated as sum of GWP (kg of CO_2eq) of each included ingredient, considering inputs needed at field level, feed processing, and transport. For soybean solvent meal, land use change was included in the assessment. Enteric methane production (g/d) was estimated [using the equation CH_4 (g/d) = 2.54 + 19.14 × DMI] to calculate CH_4 emission for kilograms of fat- and protein-corrected milk (FPCM). The data set was analyzed by generalized linear model and logistic analysis using SAS 9.4 (SAS Institute Inc., Cary, NC). The frequency distribution showed wide variation among farms for GWP (kg of CO_2eq) of TMR: approximately 25% of the surveyed farms showed a diet GWP of 15 kg of CO_2eq, 20% showed a GWP of 13 kg of CO_2eq, and 16.7% showed a GWP of 17 kg of CO_2eq. The variation among farms was due to the feedstuffs used. Among feedstuffs, soybean meal (SBM) had the highest correlation with the GWP of the TMR as shown by the following equation: TMR GWP (kg of CO_2eq) = 2.49 × kg of SBM + 6.9 (R^2 = 0.547). Moreover, diets with inclusion of SBM >15% of dry matter (DM) did not result in higher milk production than diets with a lower inclusion of SBM (≤15%). Average daily milk production of cows was 29.8 [standard deviation (SD) 4.83] kg with fat and protein contents of 3.86% (SD 0.22) and 3.40% (SD 0.14), respectively. The average DMI (kg/d) of lactating cows was 22.3 (SD 2.23). Logistic analysis demonstrated that corn silage ≤30% of diet DM was associated with higher FE. Almost 50% of farms had an average value of 15.0 g of CH_4/kg of FPCM and about 30% of farms had an average of 12.5 g of CH_4/kg of FPCM. The results demonstrated that lower enteric CH_4 production was related to inclusion (% of diet DM) of ≤12% alfalfa hay and >30% corn silage. Diets with >34% neutral detergent fiber had higher CH_4 production (>14.0 g/kg of FPCM) than those with lower neutral detergent fiber content. In contrast, lower enteric CH_4 production (≤14.0 g/kg of FPCM) was related to diets characterized by net energy of lactation (NE_L) >1.61 Mcal/kg and >4% ether extract. The variability in TMR GWP shows significant potential for reducing the GWP of a diet through choice and inclusion levels of ingredients (mainly SBM) and the possibility of decreasing methane enteric emission associated with milk production on a commercial scale.
Key words: diet composition, feed efficiency, global warming potential, enteric methane emission

INTRODUCTION

Key indicators of climate change (e.g., increased global average temperatures, changes in patterns of precipitation, increased cloud cover, and more frequent floods) are widely accepted to be due to the radiative forcing effects of increased concentrations of greenhouse gases (**GHG**) in the atmosphere. Deforestation in the tropics and consequent land use change (**LUC**) for agricultural activity is also a factor contributing to the increased emission of GHG in the atmosphere (Hopkins and Del Prado, 2007). The increase in the concentration of GHG in the atmosphere is considered mainly related to anthropogenic activities, of which agriculture and livestock production play an important role.

Using a global life cycle assessment approach, the dairy production system in 2015 was estimated to have emitted 1,711.8 million tonnes of CO_2 equivalents (**CO_2eq**), which represents about 3.2% of the total anthropogenic emissions (FAO, 2019). The dairy sector contributes to GHG emissions through enteric fer-

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mentation, manure management, and crop cultivation for feed on and off the farm (Hassanat et al., 2017; FAO, 2019). Methane emissions are by far the largest contributor to the GHG emission profile of the dairy cattle sector, accounting for about 58.5% of the total (FAO, 2019). The level of enteric methane emission is mainly determined by feed intake, composition of the diet, forage preservation, and the rate of fermentation of different carbohydrate sources in the rumen (Boadi et al., 2004). Strategies to reduce enteric CH_4 include supplementing diets with feed additives (e.g., plant extracts as condensed tannins, saponins, and essential oils) and dietary fats, offering diets rich in starch, improving forage quality, and changing the forage type used in the TMR (e.g., increased corn silage to replace grass; Little et al., 2017). Forages are one of the main components of dairy cow diets: they represent from 30 to 80% of dietary DM (Gallo et al., 2013). In the Po Plain of northern Italy, the main forages fed to dairy cattle are corn silage, alfalfa (silage or hay), and cool-season crops (silage or hay). A study conducted by Zucali et al. (2018) in 134 farms in the same area as the present study showed that corn for whole-plant silage was the crop most frequently grown as a single (83% of the farms) or double (54%) crop, followed by permanent grass hay (80%) and alfalfa (hay or silage, 58%). Because this forage is so widespread in the area and used in high amounts in lactating cow diets, it would be useful to evaluate the optimum level of corn silage to be included in the diet to optimize milk production and decrease methane emission per kilogram of fat- and protein-corrected milk (**FPCM**). Overall, the potential effect of all main ingredients included in a TMR should be considered; for example, as reported by Evans (2018), the choice of forage such as maize silage is an easy strategy to use when CH_4 mitigation is solely considered but should be questioned when associated GHG production is taken into account. Feed production, both on farm (mainly forages) and off farm (mainly concentrates), and transportation are responsible for a significant amount of GHG emission as well; for example, Bava et al. (2014) showed that emissions related to production of concentrated feed is about the 20% of total GHG impact for milk production. After emissions from enteric fermentation (accounting for 46%), therefore, feed emissions represent the second largest category, contributing about 36% of total emissions in the dairy supply chain (Gerber et al., 2013).

To the best of our knowledge, no studies or feeding models have investigated or implemented an evaluation of global warming potential (**GWP**) associated with the use of different ingredients in diets for lactating cows. In fact, GHG emission from animal feeding is not limited to enteric and manure methane emission but also to the CO_2eq associated with production of different feeds. Therefore, the aims of the present work were to (1) quantify the GWP of different lactating cow TMR commonly used in intensive farms and to identify the optimal feed ingredient composition to decrease GWP; and (2) determine the best dietary strategies to increase feed efficiency (**FE**) and reduce enteric CH_4 emission on a commercial farm scale.

MATERIALS AND METHODS

Farm Data Collection

A representative sample of 171 Italian Holstein dairy herds was selected, in the Lombardy region (northern Italy). Farms were chosen from milk producers who participated in the milk national quality control program, consisting of individual milk sample collection (every 40 d) and analysis by the extension service laboratory. Milk was analyzed for fat and protein (MilkoScan FT6000; Foss Analytical A/S, Hillerød, Denmark) in the dairy service extension laboratory. The average number of cows was 156 [standard deviation (**SD**) 116], whereas the utilized agricultural area was, on average, 84.4 ha (SD 82.3); all farms used a TMR as diet supply. Each farm was visited once for collecting data (provided by farmers) on estimated DMI, lactating cow TMR ingredient composition and chemical analysis, and milk production and composition (fat and protein content). For each farm, the amounts of homegrown forages and concentrates (commercial mixed feed and raw materials both homegrown and purchased, depending on the farm) used in the diets were recorded. For some farms that used commercial mixed feeds, the exact amount of each ingredient used in the mix was not declared by producers; hence, for these farms, the mix formula was estimated through the Cornell Net Carbohydrate and Protein System (CNCPS version 6.1; Cornell University, Ithaca, NY; Tylutki et al., 2008), based on the declared chemical composition of the mix and on the raw materials included in the formula, which were listed by the producers in a rank based on a predominance according to weight.

Chemical composition of the TMR (ash, CP, ether extract, NDF, and NFC), obtained through chemical or near infrared (NIR) analysis, was provided by farmers.

Milk production was transformed to FPCM according to the International Dairy Federation (IDF, 2015) equation:

$$\text{FPCM (kg)} = \text{milk production (kg)} \times [0.1226 \times \text{fat (\%)} \times 0.0776 \times \text{protein (\%)} + 0.2534].$$

Feed and Diet GWP Calculation

The GWP (kg of CO_2eq) of individual daily TMR was calculated as the sum of GWP of each feed ingredient. The GWP of forages (corn silage, meadow hay, and alfalfa and Italian ryegrass hay and silage) was derived from a study performed in the same geographical area by Zucali et al. (2018).

The GWP of concentrates and raw materials was obtained from the Ecoinvent (2013), Eco-Alim (2015), and AgriFootprint (2014) databases. These databases provide documented process data about environmental impact of thousands of products.

For each ingredient in diets, GWP (kg of CO_2eq/kg of DM) was calculated considering inputs needed at the field level (e.g., fossil fuel, seeds, fertilizers, pesticides, agricultural machines), feed processing (e.g., drying, ensiling) and national and transnational transport. For solvent soybean meal (SBM), direct LUC was included in the assessment. Different LUC methods result in significantly different outputs; in this study, we used the value reported by the AgriFootprint database (Soybean, at farm/BR Economic, AgriFootprint, 2014), considering 3.5 kg of CO_2eq/kg of SBM for SBM from South America. For all purchased SBM, we considered an amount of 20% from Italy and 80% from South America (ASSALZOO, 2018). For all farms, diet GWP was calculated as sum of GWP of each ingredient included in the TMR.

Enteric Methane Production

The published equations summarized by Appuhamy et al. (2016), to estimate CH_4 produced by lactating cows, were tested on a data set of in vivo trials, conducted on lactating cows fed diets based on different forages produced in the same area of the study (Colombini et al., 2015; Pirondini et al., 2015). The equation of Hristov et al. (2013) resulted in the highest coefficient of determination (R^2) value (0.880; root mean square error: 15.3) between predicted and observed values; hence, it was used to estimate enteric methane production as follows:

$$CH_4 \text{ (g/d)} = 2.54 + 19.14 \times \text{DMI}.$$

Statistical Analysis

The complete data set was analyzed using SAS 9.4 (2012; SAS Institute Inc., Cary, NC) using descriptive statistic procedures including frequency (FREQ), distribution (CHART), simple regression (REG), and means (MEAN).

The relationship between TMR characteristics (ingredients and chemical composition) and estimated enteric methane emission was evaluated through 2 multiple correspondence analyses (Proc CORRESP) to report a 2-dimensional graphical representation of the rows and columns of a contingency table. Data were analyzed by Proc GLM to test the influence of SBM (≤10%, 10–15%, and >15%), corn silage (≤30% and >30%) and corn grain meal (≤20% and >20%) inclusions and of NDF (≤34.0 and >34.0% on DM) and energy (≤1.61 and >1.61 Mcal/kg of DM) contents on ration chemical composition and milk production.

Multivariate logistic analyses were performed by LOGISTIC procedure to identify the main management factors associated with high level of FE (>1.30 kg of FPCM/kg of DMI). The threshold was chosen based on the mean of the variable in the whole data set. The logistic regression analyses examined all the possible interactions among variables. Variables or combinations of variables (interaction terms) were excluded through a stepwise backward multiple regression method based on a 20% significance level. The results of the analyses built a final model including variables (risk factors) that were significantly associated with FE (>1.3 kg of FPCM/kg of DMI). The final models were described in terms of odds ratios and 95% confidence intervals.

RESULTS AND DISCUSSION

Diet Composition

All the diets adopted by farmers were formulated to satisfy nutrient requirements for milk production according to Cornell Net Carbohydrate and Protein System (version 6.5), as described by Van Amburgh et al. (2015). Average chemical composition of TMR is given in Table 1.

Considering the main forages used in the TMR, corn silage was used in 92% of surveyed farms (Figure 1). The main reasons for such a high use of corn silage in the Po Plain are its high agronomic yield and high-energy value mainly because of its starch content. Because of

Table 1. Average nutrient composition (DM basis; % unless otherwise noted) of the lactating cow rations fed in the surveyed dairy farms

Nutrient	Mean	SD	Minimum	Maximum
CP	15.7	1.09	10.0	18.4
NDF	33.9	3.44	26.3	45.6
ADF	20.7	2.82	11.4	30.0
NFC	39.8	3.35	29.8	49.9
Starch	27.2	2.99	14.2	35.7
Ether extract	3.89	1.11	0.71	8.13
Ash	7.28	1.58	4.37	13.1
NE_L (Mcal/kg)	1.61	0.14	1.19	1.96

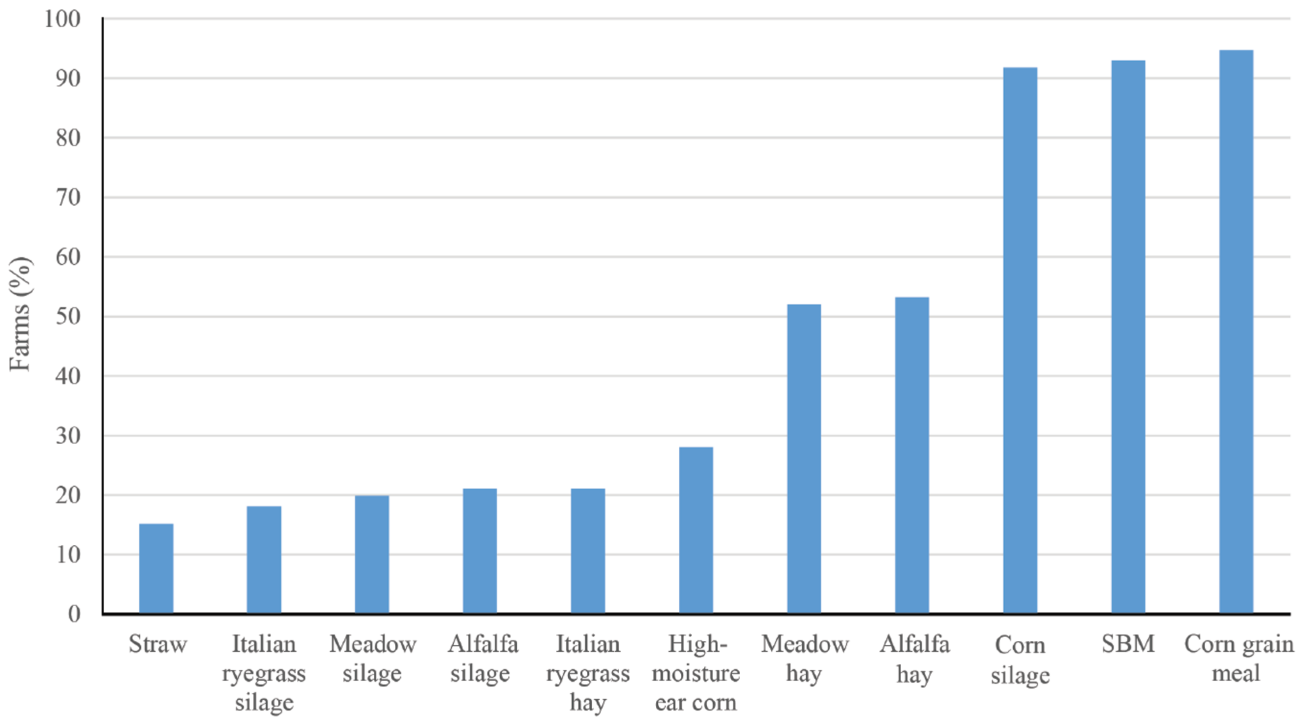

Figure 1. Utilization of main ingredients (% of farms that use the feed) for lactating cow TMR formulation. SBM = soybean meal.

its high starch content, corn silage is considered a good source of ruminally fermentable carbohydrates (Dhiman and Satter, 1997; Brito and Broderick, 2006).

As reported in Figure 2, corn silage was used in significant amounts representing, on average, 29.6% (SD 11.1%) of the diet (on a DM basis). This value is similar to that (29.0%) reported by Pirondini et al. (2012) for commercial dairy farms of the Po Plain and much higher than the value (15%) reported by Arriaga et al. (2009) in the Basque Country. This confirms that environmental conditions in northern Italy are favorable to the production of corn silage, as also reported by Zucali et al. (2018).

The other forages used in TMR were Italian ryegrass and meadow and alfalfa hays; they were used in 21, 52, and 53% of the farms, respectively (Figure 1). The average inclusion (% of DM) was 9.69 (SD 8.56) for Italian ryegrass hay, 11.4 (SD 8.00) for meadow hay, and 13.0 (SD 5.79) for alfalfa hay. In contrast, these same forages preserved as silage were used on fewer farms: Italian ryegrass silage was present in 18% of farms, meadow silage in 19%, and alfalfa silage in 21% (Figure 1).

Considering concentrates, SBM was used in 93% of the farms (Figure 1). However, the amounts used in the ration (% of DM) were different; in 28% of farms, SBM was ≤10%; in 46% of farms SBM ranged from 10 to 15%; and in 26% of farms, SBM was >15%. These differences resulted in different ($P = 0.003$) CP contents of the diets: 15.3, 15.9, and 16.0% of DM, respectively. However, variation in inclusion level of SBM did not significantly affect ($P = 0.470$) milk production, which was 29.0, 29.9, and 29.2 kg of FPCM for the 3 groups of farms, respectively. Therefore, it seems that for feeding systems of northern Italy, high inclusion of SBM (>15% on diet DM) in the diet is not necessarily linked to an improvement in milk production. Similarly, Olmos Colmenero and Broderick (2006) obtained the best results for FCM yield (36.7 kg/d) with inclusion of 9.2% SBM (DM basis), in addition to 25% alfalfa silage.

Corn grain meal was used in more than 95% of the surveyed farms, compared with high-moisture ear corn that was used in only 28% of the farms, with dietary inclusion (% of DM) of 13.7 (SD 8.98) and 5.23 (SD 8.81), respectively (Figure 1). The availability of carbohydrates for ruminal microbes and the host animal is affected by grain source and processing (Ekinci and Broderick, 1997). Compared with corn grain meal, high-moisture ear corn, due to the fermentation process, has a greater starch rumen degradability and, thus, greater digestibility (McCaffree and Merrill, 1968; Clark and Harshbarger, 1972). Cows fed high-moisture ear corn show higher milk yield than those fed corn grain meal (Clark et al., 1973; De Brabander et al.,

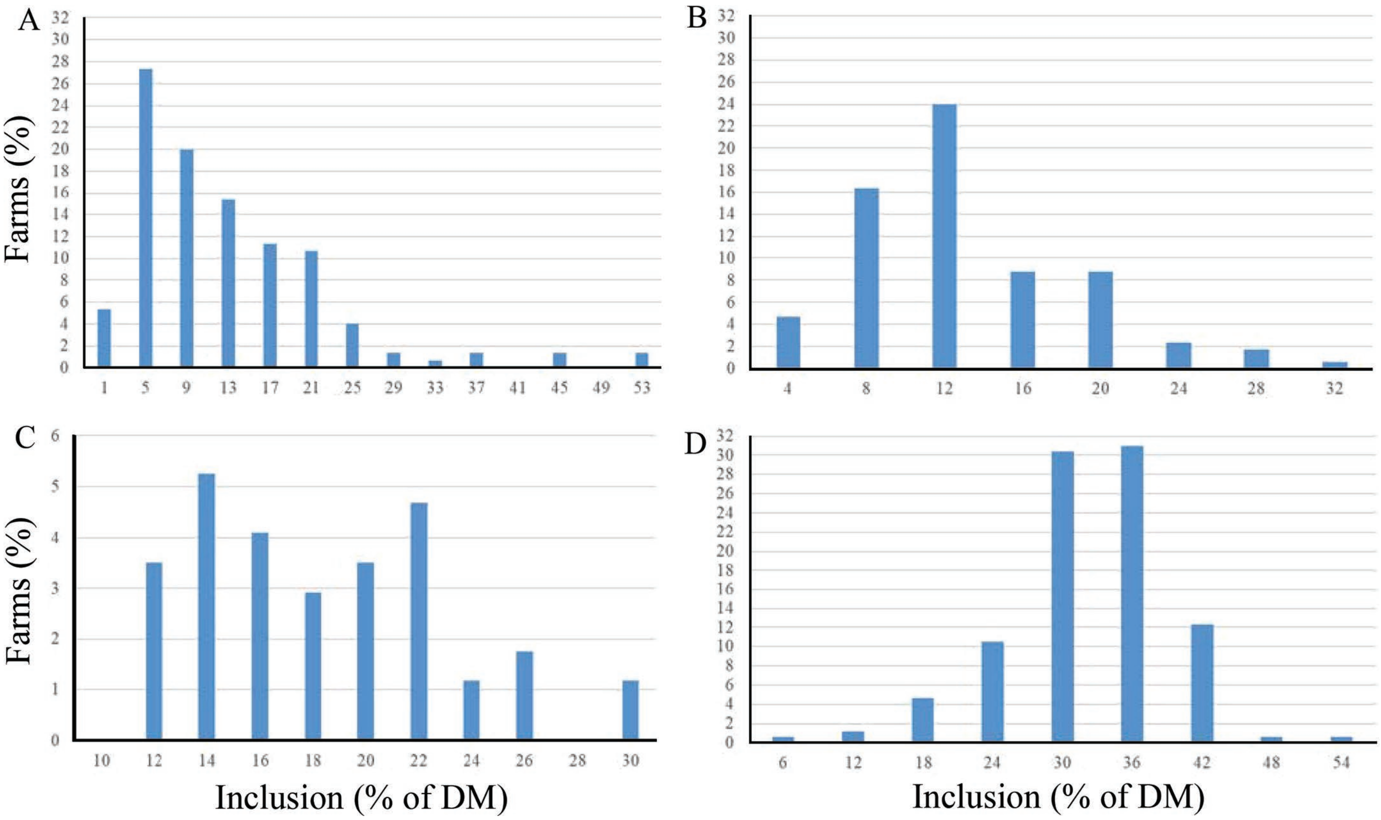

Figure 2. Level of inclusion (% of DM) in the lactating cow TMR of the main ingredients in the studied farms: (A) Italian ryegrass and meadow hay; (B) alfalfa hay; (C) high-moisture ear corn; (D) corn silage

1992). Therefore, the use of high-moisture ear corn may be increased in dairy farms because of promising results in terms of milk production and earlier harvest than for the production of dry corn meal.

Diet Composition and GWP

Diet GWP corresponded to an average of 0.61 (SD 0.15) kg of CO_2eq/kg of DM, with an average value of 13.7 (SD 3.71) kg of CO_2eq for the total daily administered TMR (Figures 3 and 4). However, wide variation was found among farms for these values: more than 26.3% of the surveyed farms showed an individual daily diet GWP of 15 kg of CO_2eq, 20% of the farms showed a GWP value of 13 kg of CO_2eq, and more than 17.7% of farms had a GWP of 17 kg of CO_2eq. These reported values are those with the highest frequency; however, approximately 28% of farms were characterized by low GWP (<11 kg of CO_2eq) and a smaller percentage of farms (8.74%) by GWP >17 kg of CO_2eq.

The variation among farms for TMR GWP is due to the feed ingredients used and to feed production and transportation, which are presumed responsible for the high amount of GHG emissions (Ogino et al., 2007). According to FAO (2019), emissions (CO_2 and N_2O) from feed production, processing, and transportation account for 29.4% of total emission from the dairy sector.

The variability of GWP among diets is directly related to their feed composition and to the GWP of each feed. For example, using concentrates to lower CH_4

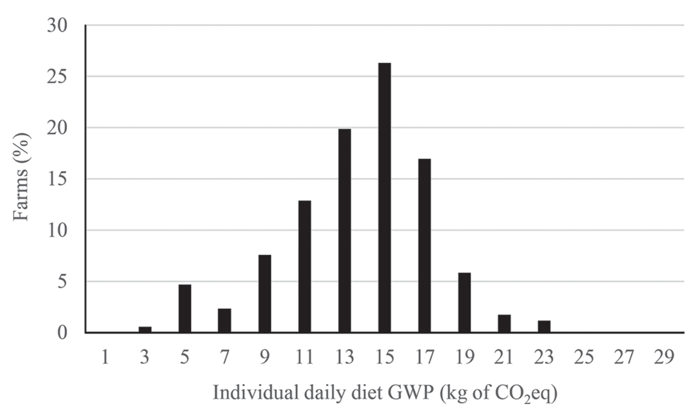

Figure 3. Frequency distribution (% of farms) of daily diet global warming potential (GWP; kg of CO_2 equivalents) in the studied farms.

emissions in ruminants could have limited advantages because increased dietary concentrates might increase total net emissions. Using a large amount of concentrates requires huge inputs for growing, processing, and transportation, leading to increased use of pesticides, fertilizers, and ancillary sources of emissions associated with production and transportation infrastructure (Beauchemin et al., 2008) and change of land use. Ogino et al. (2007) reported that production and transportation of concentrates for animal feeding produced 2.1 times as much CO_2 as that of roughage per unit of total digestible nutrient.

Considering forage ingredients, as previously reported, corn silage was the main forage source of the studied TMR. However, compared with alfalfa silage, corn silage implies greater CO_2 emission due to increased energy demand for its production that can be attributed to cropping practices, including use of fertilizers, lime, and herbicide (Little et al., 2017). Planting perennial forages such as alfalfa, moreover, might reduce agricultural GHG emissions by sequestering CO_2 in agricultural soils (Jarecki and Lal, 2003). Although changes in soil carbon can affect the carbon footprint of agricultural systems, they are rarely included in GHG analysis of dairy products because of the complexity and lack of consensus about the methodology (Little et al., 2017). Even in this study, carbon soil sequestration was not taken into account in evaluating the environmental impact of different feed sources; if we were to consider this aspect, the results obtained may change.

As previously reported, soybean meal was used in 92% of surveyed farms to satisfy the protein requirements of cows. Use of protein sources like SBM that generally comes from outside the farm (mostly South America) implies an addition in CO_2 emission related to transport and LUC. In this study, the GWP value for SBM was 3.09 kg of CO_2eq/kg of DM (AgriFootprint, 2014 modified; http://www.agri-footprint.com) and included the environmental impact of 80% of SBM being imported from South America and 20% of SBM produced locally, because Italy is not self-sufficient for this production. As expected (Figure 5), there was a linear correspondence between increasing daily diet GWP (kg of CO_2eq) and increasing the amount of SBM in the ration. Although pasture expansion remains, by far, the primary direct cause of Amazonian deforestation, the increase in mechanized crop production such as for soybeans must also be viewed as a driver of deforestation, even if new fields only replace existing pastures or savannah lands (Arima et al., 2011). In some Brazilian states such as Mato Grosso, the increase in soybean crop in regions previously used for pasture may have displaced pastures further north into forested areas, causing indirect deforestation. Therefore, soybean cultivation may still be one of the major causes of deforestation in the Legal Amazon (Barona et al., 2010; Lapola et al., 2010; Arima et al., 2011).

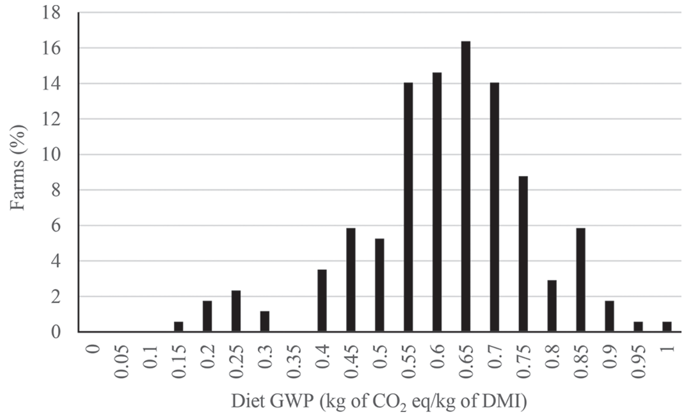

Figure 4. Frequency distribution (% of farms) of diet global warming potential (GWP) for kilograms of DM in TMR (kg of CO_2 equivalents/kg of DM) in the studied farms.

Diet Composition and Feed Efficiency

Knowledge of feed efficiency at the herd level is an important aspect that should be evaluated to increase farm profitability. In this regard, the choice of ingredients used to formulate TMR can strongly affect FE values. For example, as reported by Phuong et al. (2013), fiber, concentrate proportion, and digestible energy are the common nutritional factors affecting FE. For this reason, we studied the relationship between diet composition and FE through logistic analysis at the commercial farm scale. Average milk production of the

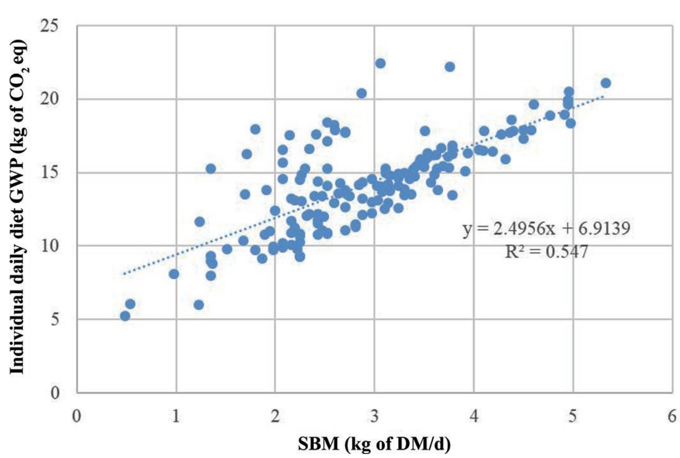

Figure 5. Relationship between dietary soybean meal amount (SBM; kg/d) and individual daily global warming potential (GWP; kg of CO_2 equivalents) of the TMR in the studied farms.

Table 2. Logistic analysis of feed sources related to high feed efficiency level (>1.30 kg of FPCM[1]/kg of DMI)

Effect	Odds ratio estimate	95% CI	*P*-value
Corn silage inclusion: ≤30% vs. >30% of DM	2.35	1.14–4.85	0.021
Corn grain meal inclusion: ≤20% vs. >20% of DM	2.10	1.11–3.97	0.022
Forages excluding corn silage: ≤20% vs. >20% of DM	2.03	1.00–4.13	0.051

[1]Fat- and protein-corrected milk.

surveyed farms was 29.8 (SD 4.83) with fat and protein contents (%) of 3.86 (SD 0.22) and 3.40 (SD 0.14), respectively.

In this study, FE was affected by dietary amount (% of TMR DM) of corn silage, other forage sources, and corn grain meal (Table 2). In particular, corn silage at ≤30% of DMI associated with the inclusion in the diet of other forage sources (e.g., alfalfa and grass hay) resulted in greater FE (Table 2). This result is in accordance with other studies, which demonstrated that a mix of different forage sources leads to an optimum balance in terms of energy and protein supply for milk production compared with either corn silage or another forage as the sole component of the forage (Dhiman and Satter, 1997; O'Mara et al., 1998; Brito and Broderick, 2006).

As described previously, corn silage is the main ingredient of lactating cow TMR in the Po Plain; however, the results of the present study confirm that a threshold level (approximately ≤30%) exists that should be taken in account when formulating lactating cow diets. Farms with <30% of corn silage included in the diet (% of DM) showed an average FPCM production of 30.2 kg/d, whereas those with >30% inclusion had an average FPCM production of 29.0 kg/d ($P = 0.099$, for the difference in milk production according to corn silage inclusion).

The results shown in Table 2 indicate that an FE >1.30 is linked to inclusion in the diet of corn silage ≤30%, corn grain meal ≤20%, and forages excluding corn silage ≤20% (odds ratios >1). Hence, an excessive increase in corn grain meal in the diet is not related to any productive advantage for the animals. In the surveyed farms, therefore, FPCM production averaged 30.1 (SD 4.82) kg/d for the group with ≤20% (% DM) corn grain meal, and 28.8 (SD 4.39) kg/d for those farms with >20% of corn grain meal in the diet ($P = 0.073$). According to Powell et al. (2016), feeding more corn grain meal does not significantly affect milk production (kg of FPCM/cow per day). Similarly, a review based on a meta-analytic approach to evaluate the effect of dietary starch on lactation performance by dairy cows (Ferraretto et al., 2013) showed that milk fat content decreased as dietary starch content increased and that milk fat depression in high-starch diets is likely related to greater starch and lower NDF intakes (Jenkins and McGuire, 2006).

Diet Composition and Enteric Methane Emission

The study was conducted on 171 commercial farms; hence, it was not possible to determine CH_4 emission by direct measurement. The level of enteric methane emission is mainly determined by feed intake and by the composition of the diet (Boadi et al., 2004; Beauchemin et al., 2008; Martin et al., 2010); thus, in the present study, methane emission was estimated according to DMI using the equation of Hristov et al. (2013). The average value of DMI of lactating cows measured by farmers in the study was 22.3 (SD 2.23) kg/d. The results are reported as grams of methane/kilogram of milk production and composition (FPCM). Differently from methane, FPCM was measured directly by farmers; thus, the obtained results can provide useful information for the area of the study to rank farms and dietary strategies to evaluate CH_4 emission per kilogram of FPCM.

As shown in Figure 6, most of the considered farms (almost 50% of those investigated) had an average value of 15.0 g of CH_4/kg of FPCM, followed by about 30% of farms with enteric methane production of 12.5 g of CH_4/kg of FPCM. These values are in line with results obtained in several trials conducted using respiration chambers (Benchaar et al., 2014; Hassanat et al., 2013, 2017). The wide variability among commercial farms for emissions shows that for a significant number of farms, emissions can be decreased by applying appropriate dietary strategies. For example, as shown in Figure 7, low enteric CH_4 (≤14 g of CH_4/kg of FPCM) production was related to the inclusion of ≤12% of alfalfa hay, >30% of corn silage, and ≤20% of other forage sources excluding corn silage (i.e., Italian ryegrass and permanent meadow). Hassanat et al. (2013) demonstrated that feeding dairy cows corn silage as total replacement of alfalfa silage involves less CH_4 emissions (in terms of g/kg of DMI). Similarly, Aguerre et al. (2011) reported a higher CH_4 emission per kilogram of both milk and ECM with increased forage proportion in the diet, in agreement with our results. Overall, the inclusion of corn silage in the diet (about 30% dietary

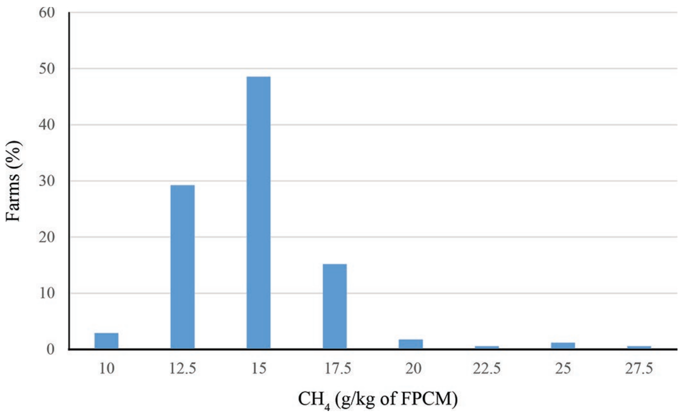

Figure 6. Frequency distribution (% of farms) of estimated enteric methane production per unit of fat- and protein-corrected milk (FPCM) in the studied farms.

DM) seems to be positively related to lower methane emission; however, as shown previously, the amount of corn silage used in the rations should not reduce the FE. This agrees with the results of van Gastelen et al. (2015), who showed lower methane emission by cows fed diets with corn silage instead of grass silage, although the calculated FE was lower for cows fed diets based on corn silage as sole forage source. The increase in dietary corn silage proportion is generally associated with some changes in the rumen, such as lower pH and acetate:propionate ratio, and reduced fiber digestibility (Hassanat et al., 2013), which can negatively affect cow performance.

Diets characterized by a high content of NDF, conversely, involve higher methane production at the enteric level. Roughage-based diets favor acetate production and increase CH_4 per unit of fermentable OM (Johnson and Johnson, 1995). As shown in Figure 8, diets with >34% NDF (% of DM) resulted in enteric methane production >14 g/kg of FPCM. In the surveyed farms, cows fed diets with a lower NDF concentration (≤34.0%) produced approximately 15.0% more FPCM (31.6 kg/d) than cows fed diets with higher NDF (>34.0%), which produced 27.2 kg of FPCM/d; this difference was significant ($P < 0.001$). In contrast, DMI was on average about 5% higher for cows fed diets with NDF ≤34.0% than for cow fed diets with NDF >34.0% (22.8 vs. 21.7 kg/d for low- and high-NDF di-

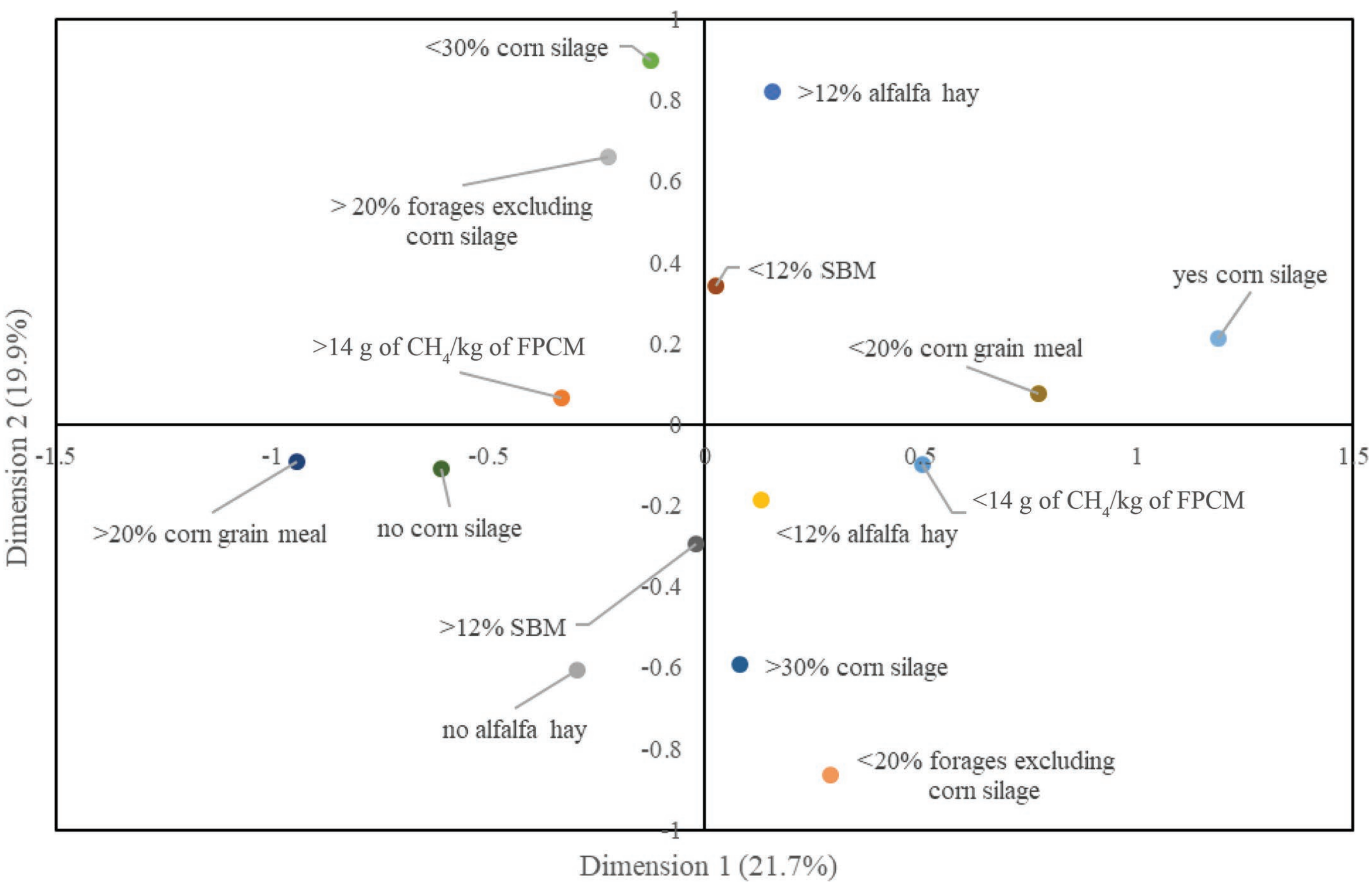

Figure 7. Correspondence analysis for methane production per kilogram of fat- and protein-corrected milk (FPCM) and feed inclusions (on DM basis) in the diet. SBM = soybean meal.

ets; $P = 0.002$); hence, cows fed diets with a high NDF content were less efficient overall, resulting in higher production of CH_4/kg of FPCM.

Similarly, as shown in Figure 8, diets characterized by more than 1.61 Mcal of NE_L/kg tended to have ≤14 g of CH_4/kg of FPCM. Diets high in energy were formulated with a slightly higher concentrate inclusion (48.9 vs 46.4% on a DM basis, respectively, for high- and low-energy diets; $P = 0.03$) and consequently higher FPCM production (30.9 vs 28.2 kg/d; $P < 0.001$). Replacing structural carbohydrates from forages in the diet with the nonstructural carbohydrates contained in most energy-rich concentrates is associated with increases in feed intake, higher rates of ruminal fermentation, accelerated feed turnover, and a shift of VFA production from acetate toward propionate, which results in lower CH_4 production (Johnson et al., 1996; Hegarty and Gerdes, 1999; Martin et al., 2010).

Similarly, lower enteric methane production was related to diets containing >4.0% (DM basis) ether extract (Figure 8), which increases the dietary energy content. Moreover, dietary fat seems to act as a reducer of ruminal methanogenesis without affecting other ruminal parameters (Martin et al., 2010). In this regard, Giger-Reverdin et al. (2003) demonstrated that an increase of 1% dietary ether extract decreased methane production by 0.68 L/kg of DM of feed. Similarly, considering methane/FPCM, Knapp et al. (2014) showed (by meta-analysis) that increasing ether extract content in the ration reduced CH_4/ECM, and this appeared to be achieved by dilution of fermentable carbohydrates in the DM and potentially reduced DMI (Knapp et al., 2014). The threshold value of ether extract of 4% on a DM basis was chosen to divide farms into 2 numerically equivalent groups. The data obtained indicate that increasing the ether extract content of the diet above

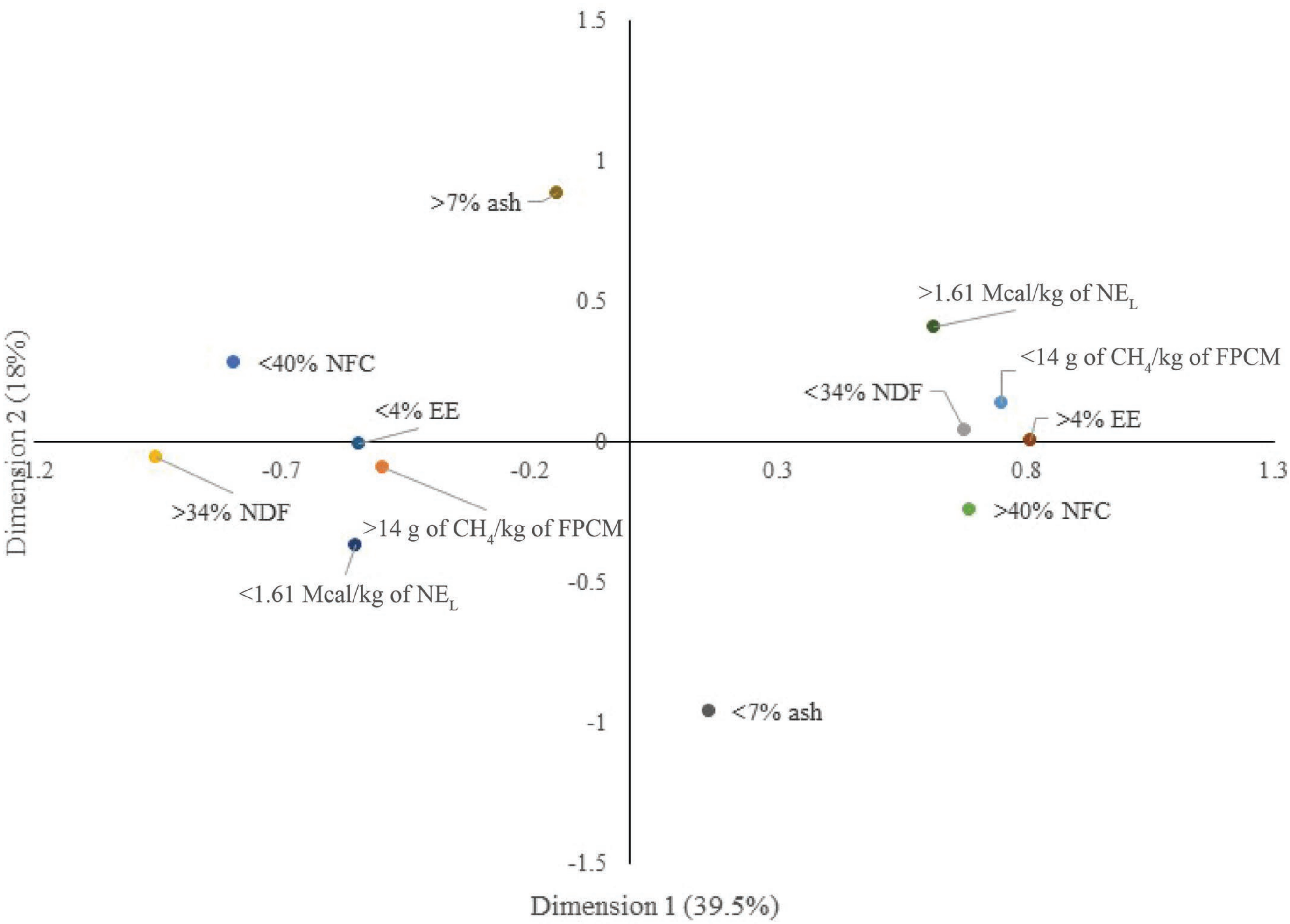

Figure 8. Correspondence analysis for methane production per kilogram of fat- and protein-corrected milk (FPCM) and chemical composition and energy content (on DM basis) of the diet. EE = ether extract.

4% is a simple but effective strategy for about half of the farms to reduce methane emission per kilogram of FPCM.

CONCLUSIONS

The results of this survey revealed that corn silage, corn grain meal, and soybean meal are the most popular ingredients included in TMR for lactating cows in northern Italy due to the high yield of corn and the high availability of the protein in soybean meal. However, the use of these feeds raises some concerns. Excessive inclusion in the diet of corn silage (>30%) or corn grain meal (>20%) is not related to higher milk yield and has a negative effect on feed efficiency. High inclusion of SBM (>15%) is not related to higher FPCM but does increase the GWP of the TMR. In contrast, it is important to consider that high inclusion of roughages in the diet results in high enteric methane production that increases the GWP of the diets. The variability in the TMR GWP obtained in this study suggests that is possible to reduce the GWP of diets and, consequently, of milk production, through correct choice of ingredients and their dietary proportion while respecting dairy cow nutrient requirements. This suggestion could be useful for formulation of diets for heifers and calves, considering their important contribution to GHG emissions. In the future, when formulating a balanced diet, it will be important to include a GWP evaluation of both the feed and of the entire TMR to contribute to the overall sustainability of livestock production.

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