Agricultural Systems 136 (2015) 106–113

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

# Substitution of corn silage with sorghum silages in lactating cow diets: *In vivo* methane emission and global warming potential of milk production

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ARTICLE INFO

*Article history:*
Received 13 August 2014
Received in revised form 5 February 2015
Accepted 15 February 2015
Available online 21 March 2015

*Keywords:*
Milk
Sorghum silage
Methane
Global warming potential
LCA

ABSTRACT

A study was conducted to determine whether sorghum silage can be a valid alternative to corn silage in lactating cow rations in terms of enteric $CH_4$ production and global warming potential (GWP) per milk unit. Diets containing corn (CS), whole plant grain sorghum (WPGS) or forage sorghum (FS) silages were fed to 6 primiparous Italian Friesian cows in a replicated $3 \times 3$ Latin square design. Diets were balanced to have 36.0 and 26.0% DM of NDF and starch, respectively. In each period cows were placed in individual respiration chambers to register $CH_4$ production. The GWP of milk production in the three different forage systems was evaluated through a "cradle to farm-gate" Life Cycle Assessment. All the emissions related to on-farm activities (forage production, fuel and electricity consumptions, manure and livestock management), off-farm activities (production of fertilizers, pesticides, bedding materials, purchased forages, concentrate feed, replacement animals, electricity, fuel) and transportation were considered. The functional unit was 1 kg FPCM. Enteric emission of $CH_4$ from cows was obtained with an *in vivo* experiment or predicted using an equation based on gross energy intake and on dietary NDF and ether extract.

Dry matter intake (kg/day) tended to be higher for CS and WPGS (20.0 for both diets) than FS (18.2) ($P = 0.07$). Milk yield was 23.6, 24.6 and 25.4 kg/day for FS, WPGS and CS, respectively ($P = 0.05$ between CS and FS).

On average, $CH_4$ from enteric fermentation and manure storage was the major contributor (45.4%) to GHG emission of milk production and 71.1% of the $CH_4$ was from enteric losses. Predicted $CH_4$ emission was slightly lower than the emission measured from *in vivo* trials (323 vs 340 g/day per cow on average). *In vivo* $CH_4$ production was not different among diets but intake energy lost as $CH_4$ was higher ($P = 0.04$) for FS (5.8%) in comparison with CS and WPGS (5.1 and 5.2% for CS and WPGS, respectively). Contribution of on-farm crop production to GWP was lower for sorghum scenarios, particularly FS, due to the reduced use of water and fertilizers. On the contrary purchased concentrate feed showed a great load on GWP (30%), especially in the FS scenario, because of the greater amount of corn meal needed to compensate for the low starch content of the sorghum silages. In conclusion the CS forage system gave higher milk production, lower $CH_4$ energy loss and lower GWP per kg FPCM than the sorghum forage systems.



## 1. Introduction

Greenhouse gas (GHG) emissions play an important role in increasing global temperature: up to 13.5% of all anthropogenic GHG emissions derive in particular from agricultural systems (IPCC, 2007). In a study of Pulina et al. (2011), on the Italian livestock sector, the contribution of animal husbandry to total GHG production was estimated at 3.2% although there is still uncertainty about the real impact of animal husbandry on GHG (Pirondini et al., 2011). About 44% of GHG emissions of the livestock sector are in the form of $CH_4$ while the remaining part is almost equally shared between $N_2O$ (29%) and $CO_2$ (27%) (Gerber et al., 2013). According to Guerci et al. (2013a) the main components of global warming potential (GWP) of cow milk production in intensive systems are: emissions from barns, manure storage and handling (together 50.1% of the total GHG) and emissions for production and transportation of purchased concentrate feeds (together 21.2% of the total GHG).

Diet manipulation is the most direct method of lowering $CH_4$ emissions from ruminants (Beauchemin et al., 2008). In general enteric $CH_4$ emissions are predicted from the chemical analysis of the diet through several equations (Ellis et al., 2007; Hristov et al., 2013; Moraes et al., 2014); however, these equations do not seem

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http://dx.doi.org/10.1016/j.agsy.2015.02.006
0308-521X/

accurate and appropriate for all feeding situations (Hindrichsen et al., 2005). For example, IPCC (2006a) published guidelines are used for official estimates of $CH_4$ emission, but Kebreab et al. (2008) showed that $CH_4$ emissions inventories are more accurately estimated through diet-specific mechanistic models. Similarly, Chagunda et al. (2010) stated that, in order to mitigate $CH_4$ emissions in a way acceptable for both the environment and animal welfare, it is important to quantify the effects of different diets on methane emissions. For example, replacing corn silage with grass silage increases $CH_4$ emission from dairy cows (Doreau et al., 2012; Mills et al., 2001) mainly as a consequence of the different starch and fiber contents of the diets. Other results suggest that a remarkable difference in dietary starch concentration is required to alter ruminal methanogenesis (Hassanat et al., 2013).

Overall, current models may give inaccurate estimates of $CH_4$ emission levels because they cannot predict the wide range in enteric $CH_4$ emissions as affected by dry matter intake (DMI) and type of diet. Additional studies are needed to better define the interactions between DMI, quality and intake of forages and $CH_4$ emissions.

Production of feed for livestock is another factor that contributes to GHG emission directly because of fossil fuel inputs (cultivation, transportation and feed processing) and indirectly through land-cover change both for grazing and feed cultivation (Vermeulen et al., 2012). Steinfeld et al. (2006) estimated that more than half of the total energy consumed in livestock production is used for feed production and that about 20% of the 80 million tonnes of nitrogen fertilizers produced annually are used to produce livestock feed. Five of the most widely grown crops in the world which can be used as animal feed are wheat, corn, soybean, barley and sorghum (FAO, 2012). Among these crops, a modeling study (Lobell and Field, 2007) showed that for wheat, corn and barley there is a clear negative response of global yields to increased temperatures (since 1980s) while for sorghum, the effect is less pronounced.

Sorghum is increasing in popularity as a silage crop, primarily because it requires less water and agronomic inputs than corn (Marsalis et al., 2010). Considering that competition for depleting resources (for example water, fossil fuel, etc.) is now widely seen as the foremost challenge of our time (Vermeulen et al., 2012), sorghum can be a valuable alternative low-input crop for dairy cattle feeding. Northern Italy dairy farming systems are characterized by a high number of cows per hectare (Guerci et al., 2013b); hence, the use of crops with high DM yield and net energy is mandatory. Amodeo (2007) reported average yields of 18.8 and 13.2 t DM/ha for corn and sorghum forage silages in the Po plain and sorghum ranked second in yield among all tested forages. Colombo et al. (2007) reported a lower average net energy value (4.91 MJ $NE_l$/kg DM) for sorghum forage varieties harvested in the North of Italy as compared to the average value (5.51 MJ $NE_l$/kg DM) reported by Spanghero et al. (2009) for corn silage harvested in the same area. However, dairy cattle fed sorghum silage gave similar milk production as corn silage (Aydin et al., 1999; Grant et al., 1995; Oliver et al., 2004).

The objectives of our study were: (1) to determine the effects of replacing corn silage with grain sorghum and forage sorghum silages in dairy cow diets on *in vivo* enteric $CH_4$ production measured in respiration chambers; (2) to compare the global warming potential of milk production in three forage system scenarios, based on corn, sorghum grain and sorghum forage silages, using predicted or *in vivo* measured enteric methane emissions.

**Table 1**
Composition of the experimental diets (% of DM).

| | Diet[a] | | |
|---|---|---|---|
| | CS | WPGS | FS |
| Ingredient composition | | | |
| Corn silage | 41.5 | – | – |
| Grain sorghum silage | – | 36.7 | – |
| Forage sorghum silage | – | – | 28.0 |
| Alfalfa pellets | 13.6 | 13.6 | 13.6 |
| Wheat straw | 1.3 | 1.3 | 1.3 |
| Corn meal | 16.0 | 21.3 | 29.4 |
| Soybean meal | 7.0 | 7.0 | 7.0 |
| Concentrate mix[b] | 17.8 | 17.8 | 17.8 |
| Salt[c] | 2.6 | 2.6 | 2.6 |
| Vitamin–mineral mix[d] | 0.2 | 0.2 | 0.2 |
| Chemical composition | | | |
| DM, % | 55.5 | 53.6 | 61.8 |
| Ash | 7.1 | 7.8 | 9.7 |
| CP | 16.0 | 17.0 | 16.8 |
| Metabolizable protein[e] | 10.9 | 10.9 | 11.0 |
| EE | 4.2 | 4.3 | 4.2 |
| NDF | 36.6 | 35.8 | 37.0 |
| ADF | 19.5 | 21.2 | 21.4 |
| Starch | 26.5 | 26.8 | 25.0 |
| Gross energy, Mcal/kg DM | 4.49 | 4.50 | 4.37 |
| $NE_L$[e], Mcal/kg DM | 1.71 | 1.68 | 1.63 |

[a] CS = corn silage diet; WPGS = whole plant grain sorghum silage diet; FS = forage sorghum silage diet.
[b] Concentrate mix: 21% canola meal, 21% cotton seeds, 20% beet pulp, 19% barley meal, 8% soybean flakes, 8% sugar cane molasses, 2% urea, 1% yeast.
[c] Salt: 30% sodium bicarbonate, 18% calcium carbonate, 18% potassium carbonate, 12% monocalcium phosphate, 9% potassium sulfate, 9% magnesium oxide, 4% sodium chloride.
[d] Provided (per kilogram): 17.5 mg of Zn, 1.75 mg of Cu, 0.75 mg of Mn, 0.3 g of I, 0.13 g of Se, 0.02 g of Co, 1900 KIU of vitamin A, 600 KIU of vitamin D, and 16 KIU of vitamin E.
[e] Calculated according to the Cornell Net Carbohydrate and Protein System (CNCPS) version 5.

## 2. Materials and methods

### 2.1. *In vivo experiment: animals, experimental design and diets*

Composition of the diets is reported in Table 1. Three diets were tested based upon: corn (CS), whole plant grain sorghum (WPGS) or forage sorghum (FS) silages. Corn and sorghum crops were sown in adjacent parcels in Northern Italy (Po Plain) in June, after Italian ryegrass harvest, and were harvested at the beginning of October. All crops were irrigated by flooding; corn was irrigated 4 times while both sorghum crops were irrigated twice. Fertilizers were applied only in the corn-Italian ryegrass cropping systems; in particular the rates were: 200 N-urea/ha; 100 N-NPK/ha; 50 P-NPK/ha; 130 K-NPK/ha.

Diets were formulated using the CNCPS model version 5 (Fox et al., 2004) and balanced to contain 11.0, 36.0 and 26.0% DM of metabolizable protein (MP), NDF and starch, respectively. Because of the different fiber and starch concentrations (NDF: 39.5, 45.2 and 62.5% of DM; starch: 31.5, 20.8 and 3.4% of DM for corn, sorghum grain and sorghum forage silages, respectively) the three forages were included in the experimental diets in different proportions, as well as the corn meal necessary to compensate for the low starch content of the sorghum silages. Cows were fed the experimental diets in a 3 × 3 repeated Latin square design and each cow was fed the 3 diets in 3 consecutive periods of 28 days (21 days of adaptation and 7 days of sample collection and data registration). Animals on trial were handled as outlined by the guidelines of the Italian law for the animal welfare of experimental animals (Italian Ministry of Health, 1992). During the experimental periods, cows were housed in individual respiration chambers to measure $CH_4$ emission.

More details on the experimental design and sample analyses are reported in the companion paper (Colombini et al., 2012).

### 2.2. *Methane measurement*

Three air-flow controlled chambers were used for measuring $CH_4$ production. The chambers measured 3.6 m length × 2.4 m