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RESEARCH ARTICLE

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Using manure as fertilizer for maize could improve sustainability of milk production

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Abstract

This study evaluated the effect of organic or chemical fertilization of maize on cow performance, economic outcomes, and greenhouse gas emission. Each type of maize silage according its different fertilization was used in two rations offered to two different groups of nine Friesian-Holstein cows throughout 4 months. The production cost of the maize silage was 8.8% lower for organic than for chemical fertilization. Both silages had similar nutritive value, except a higher concentration of starch in maize with organic fertilization, which allowed a reduction in the proportion of concentrate in the ration, saving 25.3 eurocents per cow in the daily ration, generating a positive balance of 21.8 eurocents per cow and day. The milk yield and composition were unaffected depending on the type of fertilization, whereas the estimation of CH_4 and N_2O emissions with chemical fertilization was higher than emissions with organic fertilization. As a result, it is possible to increase the sustainability and profitability of dairy production with reuse and recycling of manure.

Additional keywords: organic fertilization; maize silage; dairy cow; production costs; greenhouse gas emissions.

Abbreviations used: ADF (acid detergent fiber); ChF (chemical fertilization); CP (crude protein); DM (dry matter); DMI (dry matter intake); EF (emission factor); GHG (greenhouse gas); GWP (Global Warming Potential); IPCC (Intergovernmental Panel on Climate Change); MnF (organic fertilization); NDF (neutral detergent fiber); NE (net energy of lactation); PMR (partial mixed ration).

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Introduction

Currently there is a growing interest in steering livestock production towards more sustainable systems. The recent end of the milk quota system in Europe after 30 years has coincided with an increase in the price of agricultural commodities along with lower price of raw milk. This fact has forced dairy farmers to reduce costs, improving the efficiency in the use of their own resources. Maize silage provides a relatively low cost source of energy, in the form of starch and fiber which complements pasture (Kolver *et al.*, 2001), because it provides a high proportion of grain and relatively digestible fiber. The high content of starch in maize has led to a high appreciation of its value mainly in dairy farming, and the low crude protein concentration of maize silage makes it an ideal component in protein-rich grass-based rations. From a livestock perspective, the benefit of maize silage can be achieved when it is used as a supplement to pasture, not as substitute for it (Macdonald, 1999), because the increase in maize cultivation area causes a large increase in greenhouse gas emissions by ploughing vast areas of grassland (Vellinga *et al.*, 2004). The profitability of any supplementary feeding system is highly sensitive to the price of milk and supplements, and the different associated costs, especially labour (Macdonald, 1999).

The crop rotation maize-Italian ryegrass is continuously used in many of dairy farms located in areas that allow the mechanization of plots, due to their high potential of dry matter yield. Maize silage is the main constituent of lactating dairy cow diets in many American and European farms, representing between 300 and 800 g/kg of forage dry matter content of diets (Gallo *et al.*, 2016). This rotation needs high amount of N fertilization that has negative effects on the soil (Heinze *et al.*, 2011). The excessive use of N fertilization causes a huge change in ecosystems, incurring in soil degradation contamination of groundwater and atmosphere, which causes a progressive decrease of the soil organic matter content, affecting its physical, chemical and microbiological properties (Caravaca *et al.*, 2002). The abuse of N fertilization has caused major environmental problems because the plants cannot assimilate all the N supplied and hence between 50 and 70% of N is transferred to the ecosystem, causing water pollution, eutrophication (Good & Beatty, 2011), and even generating biologically dead zones (Bristow *et al.*, 2017). The efficiency of chemical fertilizer used in maize silage cropping has become a major concern, as the crop is often negatively connoted to N-aspects of surface and groundwater quality (Schröder *et al.*, 2000). External inputs of N and phosphorus on the farms should be reduced for environmental and economic reasons. At present, the production of quality forages must be environmentally and ecologically sound and aligned with public values, because the livestock production account for about 9% of total anthropogenic greenhouse gas (GHG) emissions (IPCC, 2014).

Manure and slurry application to crop fields can recycle animal wastes and be a valuable source of nutrient. A large proportion of the dairy manure is applied to land in maize production for silage. The benefit of dairy manure application on maize silage production has been reported (Butler *et al.*, 2008), and can be attributed to the improvement of physical and chemical edaphic properties (Butler & Muir, 2006) and to an increased P (19%) and K (21%) uptakes in maize (Singer *et al.*, 2007). However, proper manure management is important when livestock densities are high and could potentially lead to high N-loading rates to agricultural land. The objective of this study was to evaluate the effects of the application of organic (manure) or chemical fertilization on maize yield, silage quality, cows' performance, as well as on the feeding costs, economic outcomes, and on the emission of nitrous oxide and enteric methane.

Material and methods

Study area and crops

The study was undertaken at the experimental farm of SERIDA (Villaviciosa, Spain), located at N45°28'50", W5°26'27" and 10 metres about sea level. Two adjacent plots of 1.7 ha each were sown with maize (*Zea mays* cv. LG3377) as summer crop, using chemical (ChF) or organic (MnF: manure) fertilization respectively. Both plots were sandy-loam type soil. The ChF plot had 79.1% of sand, 9.1% of slit and 11.8% of clay, and the MnF plot had 74.7% of sand, 15.9% of slit and 9.4% of clay. The crop rotation Italian ryegrass-maize (*Lolium multiflorum* Lam.-*Zea mays* L.) without irrigation and with chemical fertilization was repeated over the last years in both plots. The fertilization of the ChF plot for maize crop was 125 kg N/ha, 150 kg P_2O_5/ha and 250 kg K_2O/ha before sowing. When the maize plants were 20 cm high, 75 kg N/ha, as 27% of calcium ammonium nitrate with 2% of magnesium, were applied as topdressing. The MnF plot was fertilized with manure deriving from the SERIDA dairy herd. The manure was analyzed previously, and had 3.24 kg N/t, 1.93 kg P_2O_5/t, 6.23 kg K_2O/t and 1.34 kg MgO/t. The application of organic fertilization was performed in such a way that the total N was close in both treatments and, if the N concentration were not enough, complemented with the minimum amount of synthetic fertilizer. Consequently, 45 t/ha of manure were applied before sowing the maize. The N deficit was supplied by the application of 50 kg N/ha as topdressing when maize plants were 20 cm high. The weeds were controlled in both managements with the application of 2 L/ha of herbicide (Harness Plus, Monsanto Co., Creve Coeur, MO, USA) and pest control with organophosphate insecticide (Chlorpyrifos 480 g/L; Dursban 48, Syngenta AG, Basel, Switzerland). Both types of maize were harvested on October 2011, when the maize grain was doughy-vitreous, and ensiled into trench silos of 30 m^3, two silos by each type of silage. The silos were opened on February 2012.

Animals and diets

Eighteen Holstein cows, with two to five lactations, were selected with 137±26 days in milk (average±SE), a milk production of 24.8±5.92 kg/d, 590±33.6 kg of body weight and a body condition score of 2.56±0.103 (1 to 5 scale) at the beginning of the experiment. Cows were kept in a free stall barn with rubber mat bedding and the exercise area had concrete floor and a scraper system for manure removal. Rotational grazing was allowed for 6 hours daily in seven 1.5 ha paddocks with a wide range of grasses: *Lolium perenne* (45%), *Agrostis capilaris* (13%), *Bromus erectus* (12%), *Poa annua* (3%), *Poa trivialis* (2%) and *Dactylis glomerata* (2%); legumes: *Trifolium repens* (17%) and *Trifolium pratensis* (2%), and other species (all of them <1%) such as *Capsella bursa-pastoris*, *Diplotaxis erucoides, Stellaria media, Cerastium arvense, Rumex obtusifolius* and *Taraxacum officinale*.

The dairy cows were randomly allocated in two groups, with nine cows each one, and each group were assigned to one isoenergetic and isoproteic partial mixed ration (ChF PMR or MnF PMR), formulated according to requirements for dairy cattle (NRC, 2001). The PMRs consisted of ChF or MnF maize silage, according their type of fertilization, grass silage, barley straw and concentrate. Additionally, two concentrates, named L and S, were distributed as energy source and in order to keep the cows quiet during milking sessions. Concentrate L was provided at 2 kg/d per cow and day and concentrate S offer was supplied adjusted to milk production: 0.2 kg by kilogram of milk produced above 30 kg/d in the multiparous cows and above 25 kg/d in the first calving cows. Clean water and additional vitamin-mineral mix were always available free-choice in the barn and paddocks.

Experimental procedures

The study was conducted based on the standards of the European Union Animal Welfare Directive Number 2010/63/EU throughout 4 months between February and May 2012. Both PMRs (ChF or MnF) were done fresh daily and offered *ad libitum* indoors. The PMR intake of individual animals was automatically recorded daily by an electronic weighing system integrated to the scale pans using a computerized system. PMR refusals were removed daily. The additional concentrate intakes were recorded daily by means of the automatic feeder included in the milking system. Both silos of each type of maize were sampled before starting the experiment to formulate the PMRs according the nutritive value of silages. Samples of both PMR (ChF and MnF) were taken once weekly and, both concentrates (L and S) once monthly. Two samples of mixed herbage from grazing paddocks were collected weekly during the study, by tracing a diagonal transect across the area available prior to grazing to measure the pasture yield and availability. Each sample was composed by five quadrants (0.20 m^2 each), leaving a stubble of about 5 cm. Pasture intake was estimated weekly using Macoon *et al.* (2003) technique for estimating the forage intake of lactating dairy cows on pasture. Briefly, energy requirements were recorded as net energy (NE) requirements for maintenance, lactation, body weight changes, walking and grazing. The NE from pasture intake was estimated as total NE requirements minus the NE supplied by the PMR and concentrate intakes. The cows were weighed fortnightly after morning milking. Cows were milked twice daily at 06:30 h and 17:30 h. Milk production was measured daily in both milking sessions, and was sampled weekly in both milking sessions. After each morning milking, the cows remained indoors until 11:30 h, and then were moved to the grazing area, where they stayed until the evening milking. All cows were kept indoors overnight.

Analytical procedures

The samples of both maize silages, both PMRs and pasture were dried at 60 °C for 24 h and milled through a 0.75 mm. Concentrates were milled through a 1.00 mm. Feed samples were analyzed for dry matter (DM), ash, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and starch by near infrared spectroscopy (FOSS NIRSystem 5000, Silver Springs, MD, USA). The energy content was estimated in all samples according to ARC (1980). The volatile fatty acids and lactic acid of silages were analyses by HPLC (Waters Alliance 2690, Milford, MA, USA) equipped with a Shodex RSpak KC-811 column (Showa Denko America Inc., NY, USA) and with a Photodiode Array Detector. Separation was achieved in isocratic mode with a mobile phase containing 0.025 w/w phosphoric acid. Ammonia nitrogen was analyzed after adding MgO by Kjeldalh distillation and titration with a boric standard solution (Tecator FOSS Glechic A/S, Hillarød, Denmark). Milk samples were preserved with 0.13 mL of azidiol and analyzed for fat, protein and lactose contents (MilkoScan FT 6000, Hillerøed, Denmark).

Estimations of greenhouse gas emissions and feed cost

The method used to predict methane (CH_4) emission was IPCC Tier 2, and IPCC Tier 1 to predict N_2O emission (IPCC, 2006). The first one calculates the enteric CH_4 as dry matter intake (DMI) multiplied by the CH_4 emission factor (EF) for milking cows (CH_4=DMI×EF). The EF was estimated according to the following equation: EF=(E×Ym×d)/55.65, where E is the dietary gross energy intake (MJ/cow/day), Ym the methane conversion factor calculated from the digestibility of energy, and d are the days of measurements. The emission of methane from manure and slurry were estimated from the equation: $CH_{4manure}=0.67VS \times B_0 \times MCF \times MU$, where MU is the percentage of usage of manure, that when is stored without cover is considered as 25.2%, MCF is the methane conversion factor, that when manure is stored without cover is considered as 77% for temperate climates, B_0 is the maximum CH_4-producing capacity from manure and slurry (0.18 m^3 CH_4/kg VS) , and VS the total volatile solids excreted by animal. These were estimated from the metabolizable energy intake and organic matter of diet. The second method uses the source of N added to soil (inorganic and organic fertilizers, crop residues, and urine and manure of grazing animals). The emission factors of N_2O were considered as 0.01 kg N/ha for fertilizers and crop residues, 8 kg N/ha for grasslands in temperate climate, and 0.02 kg N/ha for urine and manure deposited in meadows by grazing dairy cows. The results were converted to carbon dioxide equivalent (CO_2eq) using the Global Warming Potential (GWP) of 25 and 298 to CH_4 and N_2O, respectively (Forster *et al.*, 2007). An economic analysis of feed cost was performed using activity budgets to obtain the mean values as described by Espinoza-Ortega *et al.*, (2007). The costs per tonne of DM of forage produced into the farm (maize silages from manure or chemical fertilization, grass silage and pasture) were obtained from the cost of crop production, including seeds, fertilizers, labour, machinery and facilities. The cost of feed purchased off-farm (barley straw and all concentrates) was calculated per kg of DM according to the current market prices.

Statistical analysis

Maize silage chemical composition variables were analysed by one-way analysis of variance, with treatment as main factor. Individual animal data of DMI, production and composition of milk and GHG emissions were analysed using the MIXED procedure of the SAS (1999) for repeated measurements, with a model considering the treatment effect (ChF or MnF) and experimental error. Individual animals were considered as experimental units. When the ANOVA was significant ($p<0.05$), means were separated by Tukey's test pairwise comparison.

Results

During maize growth (June to October 2011), daily average temperature was 17.7 °C (range: 12.0−23.5 °C) and the total rainfall was 277 mm with 53 rainy days. During the course of the animal trial (February to May 2012), daily average temperature was 10.8 ºC (range: 3.4−18.5 ºC) and total rainfall was 259 mm with 62 rainy days. The temperature data were similar to those historically recorded. However, the amount of rainfall was 27% lower than the average for the last 35 years for the same months.

The maize yield was a 20% higher in MnF than ChF treatment (13.3 *vs.* 10.7 t DM/ha respectively). The means of chemical composition and fermentative parameters are presented in Table 1. Both types of maize silage had a similar nutritive value, except the concentration of starch, that was higher ($p<0.05$) in MnF (35.5%) than in ChF (31.0%). Ammonia-N concentration and acetic acid proportion were not affected by the fertilization. The lactic acid proportion was higher in MnF silage than ChF silage (5.2 *vs*. 4.3% lactic acid, respectively; $p=0.095$). The proportions of propionic and butyric acids fall below the limit of detection. The highest starch concentration in MnF allowed making a PMR with 5.4% less of concentrate when maize silage with organic fertilization was used, in order to formulate two isoenergetic (1.51 Mcal NE_l/kg DM) and isoproteic (13.3% CP) PMRs (Table 2). The pasture had 13.4% CP, 54.5% NDF and 1.39 Mcal EN_l/kg DM. The average nutritive value of both concentrates was 19.0% CP and 1.86 Mcal EN_l/kg DM.

Table 3 shows the total DMI and the intake of each ingredient included in the diet for both treatments. No statistical differences were observed in the total DMI between treatments; although that of MnF diet was numerically 10% lower than for ChF (17.7 and 19.8 kg DM per day, respectively). This is particularly due to the lower intake of grass during grazing by animals in MnF treatment (4.3 *vs.* 5.4 kg DM/d for the MnF and ChF treatments, respectively; $p>0.05$). However, there was a lower intake of concentrate included on PMR in

Table 1. Chemical composition (% on dry matter (DM) basis) of maize silages with different fertilization: Organic (MnF) or Chemical (ChF). Values are means for n=2.

	MnF	**ChF**	**SE[1]**	***p*-value**
pH	3.75	3.62	0.072	NS
DM	35.02	35.20	1.226	NS
Organic matter	95.59	95.15	0.212	NS
Crude protein	8.54	8.97	0.324	NS
Starch	35.46	31.01	1.143	*
Acid detergent fiber	23.35	23.97	0.475	NS
Neutral detergent fiber	41.67	43.25	1.004	NS
In vivo digestibility (%)	74.33	72.85	0.857	NS
Net energy lactation (Mcal/kg DM)	1.71	1.67	1.023	NS
NH_3-N (% total N)	6.32	5.30	0.568	NS
Lactic acid	5.23	4.25	0.351	0.095
Acetic acid	3.04	3.01	0.459	NS

[1]SE: standard error. Statistical significance: * $p<0.05$; NS, not significant

Table 2. Ingredient composition (% on dry matter (DM) basis) of the partial mixed rations (PMR), based on organic (MnF) and chemical (ChF) maize silages and nutritive value (% on DM) of both PMR. Values are means for n=16.

	MnF	ChF
Ingredient		
Maize silage	30.8	31.1
Grass silage	38.8	37.5
Barley straw	7.7	7.4
Concentrate[1]	22.7	24.0
Nutritive value		
DM	44.19	45.30
Organic matter	90.03	90.03
Crude protein	13.46	13.07
Acid detergent fiber	25.78	26.90
Neutral detergent fiber	42.75	44.48
Net energy lactation (Mcal/kg DM)	1.51	1.50

[1]Roasted soybean meal (36.5% DM basis), maize flakes (28.1%), barley (17.8%), rye (9.3%), cotton seed (2.0%), fat by-pass (1.9%), beet pulp (1.3%), vitamins and minerals (3.1%).

treatment based on MnF silage than ChF silage (2.8 *vs.* 3.2 kg/d respectively; $p<0.05$) as a result of the lower inclusion of concentrate on PMR in MnF treatment as well as the lower intake of PMR in this treatment. The lower DMI of the animals in the MnF treatment was reflected in a decrease in the live weight throughout the experiment, although without differences between treatments (590 kg live weight in both groups at the beginning of the experiment, and 583 kg for the MnF treatment and 599 kg for the ChF treatment at the end of the experiment). The body condition score also changed over the experimental period (2.56 at the beginning in both treatments, and 2.45 *vs*. 2.65 at the end of the experiment for the MnF and ChF treatments respectively; $p<0.05$).

Table 3. Total dry matter intake (DMI; kg/d) of partial mixed rations (PMR), concentrates and pasture for the two treatments: diets based on maize silage fertilized with organic (MnF) and chemical (ChF) fertilization. Values are means for n=1080 for partial mixed rations and concentrates, n=144 for pasture.

	MnF	ChF	SE[1]	*p*-value
Total DMI [=(1+2+3+4)]	17.67	19.75	0.932	NS
1) PMR [=(a+b+c+d)]	12.42	13.39	1.085	NS
a) Maize silage	3.83	4.16	0.342	NS
b) Grass silage	4.82	5.02	0.427	NS
c) Barley straw	0.96	0.99	0.848	NS
d) Concentrate	2.81	3.22	0.143	*
2) Concentrate S	0.41	0.35	0.185	NS
3) Concentrate L	0.53	0.61	0.167	NS
Total concentrate [=(d+2+3)]	3.75	4.18	0.450	NS
4) Pasture	4.31	5.40	0.982	NS

[1]SE: standard error. Statistical significance: * $p<0.05$; NS, not significant

The daily averages of production and milk composition are shown in the Table 4. No differences were seen between treatments with respect to milk production (25.4 kg/d), fat (38.9 g/kg), protein (32.7 g/kg) and lactose (48.9 g/kg) contents.

The concentrate intake per kilogram of milk produced was of 142 g/kg in cows with MnF treatment, while it was of 160 g/kg in cows with ChF treatment ($p<0.05$). Feeding costs and incomes from the sale of milk for the treatments based on MnF and ChF silages are shown in Table 5. The cost of each ingredient produced on-farm (maize silages grown using organic or chemical fertilization, grass silage and forage grassland) was calculated based on the cost of crop production, involving the whole process (seed, fertilizers, labour, machinery and facilities). The production cost of tonne of DM of the maize silage with chemical fertilization was 86.5 €, while with organic fertilization was 78.9 €. The grass silage costs 69.0 €/t DM and, the estimated cost of pasture was 4.9 €/t DM. The cost of feedstuffs purchased off-farm (barley straw and concentrates) was calculated per kg of DM according to the current market prices. The price of straw was 0.114 €/kg DM and the concentrates of PMR, S and L were 0.386, 0.365 and 0.444 €/kg DM respectively. The ChF diet was more expensive than the MnF diet (2.49 *vs*. 2.24 € per cow and day respectively). This difference reflects the higher DMI of cows feeding ChF PMR than MnF PMR, as well as the higher production cost of maize silage grown using chemical fertilizers and, especially, the higher inclusion of concentrate in the PMR based on ChF silage, increasing spending on purchases of feedstuffs

Table 4. Milk yield (kg/d) and composition of milk (g/kg) for the two treatments: diets based on maize silage fertilized with organic (MnF) and chemical (ChF) fertilization. Values are means for n=1080 for milk production, n=144 for composition.

	MnF	ChF	SE[1]	*p*-value
Milk yield	25.17	25.72	2.068	NS
Fat	38.93	38.83	1.481	NS
Protein	32.68	32.65	1.273	NS
Lactose	48.86	48.93	2.100	NS

[1]SE: standard error. Statistical significance: NS, not significant

Table 5. Feeding costs and incomes from the sale of milk (€) per cow and day for the two treatments: diets based on maize silage fertilized with organic (MnF) and chemical (ChF) fertilization. Values have been calculated from average of groups of cows.

	MnF	ChF
Costs (€/day)		
1) Feedstuffs produced [=(a+b+c)]	0.656	0.733
a) Maize silage	0.302	0.360
b) Grass silage	0.333	0.346
c) Pasture	0.021	0.027
2) Feedstuffs purchased [=(d+e+f+g)]	1.580	1.755
d) Barley straw	0.109	0.113
e) Concentrate	1.086	1.244
f) Concentrate S	0.149	0.128
g) Concentrate L	0.235	0.271
Feeding costs		
h) per day [=(1+2)]	2.236	2.489
i) per kilogram of milk [=(1+2)÷kg/day]	0.089	0.097
Income		
3) Milk market prize (€/kg)	0.299	0.294
4) Milk sale (€/d) [=(3×kg/day)]	7.526	7.562
Net margin		
5) Euros per kilogram [=(3−i)]	0.210	0.197
6) Euros per cow and per day [=(4−h)]	5.290	5.073

off-farm (1.76 *vs.* 1.58 € per cow and day for cows in ChF and MnF treatments respectively).

The slightly higher fat content of cows milk in the MnF treatment (Table 4) causes a slight difference in the price paid by the dairy industry (0.299 €/kg for cow's milk in the MnF treatment *vs*. 0.294 €/kg in the ChF treatment). Although the daily gross income per cow was higher in the ChF than MnF treatment, with the different feed cost between managements, the overall net margin of profitability was 0.217 € per cow and day or 0.013 €/kg higher for cows in the MnF than for those in the ChF treatment (Table 5).

Greenhouse gas emissions per cow, per DMI and per kilogram of milk expressed as carbon dioxide equivalent are given in Table 6. More than 85% of methane emissions are due to enteric fermentation, being higher in ChF than MnF diet (817 *vs*. 714 L CH_4/cow and day respectively). The difference was diluted when it refers to DMI (41.3 and 40.4 L CH_4/kg DMI, respectively). The estimated N_2O emissions due to soil management were similar in both treatments (13.3 g N_2O/day). The prediction of total CO_2eq emission in ChF treatment was higher than MnF (up to 13%; $p<0.05$).

Table 6. Estimated emissions of carbon dioxide equivalent related to cow (kg CO_2eq per cow and day), to dry matter intake kg (CO_2eq/kg DMI) and to milk yield (kg CO_2eq/kg milk) for the two treatments: diets based on maize silage fertilized with organic (MnF) and chemical (ChF) fertilization. CO_2eq calculated from the values of the Global Warming Potential (GWP): 25 to methane and 298 to nitrous oxide (Forster *et al*., 2007). Values are means for n=9.

	MnF	ChF	SE[1]	*p*-value
Enteric fermentation	11.76	13.46	2.049	*
Manure excretion	1.23	1.55	0.228	NS
Soil management	3.78	3.95	0.122	NS
Total	16.77	18.97	1.553	*
kg CO_2eq/kg DMI	0.95	0.96	0.008	NS
kg CO_2eq/kg milk	0.67	0.74	0.050	*

[1]SE: standard error. Statistical significance: * $p<0.05$; NS, not significant

The difference observed in this study was due to the diet and not to the type of fertilization, because there were no differences in soil management nor manure excretion between treatments. There were no differences when GHG emissions were expressed to DMI, however a 10% higher production of CO_2eq per kg of milk was observed in ChF than MnF (0.67 *vs*. 0.74 kg CO_2eq/kg respectively, $p<0.05$).

Discussion

In the present work, the different fertilization of maize with organic or chemical sources affected forage yield, being higher with manure fertilization than with synthetic fertilizers. The increase in maize silage production with organic fertilization agrees with that reported by other authors who examined dairy manure, chemical fertilizer and combinations of manure and chemical fertilizer (Butler *et al.*, 2008). Manure increases soil fertility supplying K, nitrate-N and ammonia-N to aid crop production (Nevens & Reheul, 2005). The effect is higher with manure as fertilizer than slurry, because applications of slurry do not lead to such an increase of residual mineral N (Schröder, 1999). Manure N must be mineralized before it becomes available to plants (Klausner *et al.*, 1994). Therefore, in the year of application, only a portion of it was available to the crop and the remaining was carried over to subsequent years. However, the silage maize takes up a relatively low amount of N owing to the short growing season and the poor root extension. In spite of this, the forage yield in MnF could have been increased because of the higher content of organic carbon (Loveland & Webb, 2003) or available water, due to an important water retention, in manured soils (Arriaga & Lowery, 2003).

Butler *et al.* (2008) have reported higher concentrations of NDF and ADF in maize silage with organic fertilization than inorganic fertilization. However, these differences were not consistent among years. Wachendorf *et al.* (2006) reported higher concentration of CP and lower net energy in maize silage with organic fertilization, apparently because of the possible effects on competition for water and nutrients from the grass understory. In any case, all these differences were small and biologically insignificant. The nutritive value of maize silage is largely determined by the cob-stover ratio. Although the proportion of cob was not measured in this experiment, previous work carried out reported a higher percentage of cob in maize silage produced with organic fertilization than chemical fertilization (Martínez-Martínez *et al.*, 2009). There have been also reported higher maize grain yield from manure as compared to fertilizer (Eghball & Power, 1999). In the present work, the application of organic fertilization did not change the nutritive value of maize silage, except the starch concentration, an indicator of the high cob production, which was higher in MnF silage than ChF silage. A higher concentration of starch means more lactic fermentation capacity (Mogodiniyai Kasmaei *et al.*, 2013), which would explain the higher concentration of lactic acid in MnF silage than ChF silage, which is a guarantee in the fermentation process. The higher concentration of starch in MnF leads to slightly higher energy values. This allowed making a PMR with 5.4% less of commercial concentrate in MnF treatment than ChF treatment. When the cost of concentrate is high relative to the price of the animal product, one of the potential benefits of including alternative forage is the potential to maintain animal performance whilst reducing concentrate feed level. This saving in feeding costs with the MnF diet comes in addition to a substantial saving in the cost of maize silage from organic fertilization, circa 9%. The maize silage is produced at 20% higher costs than 3-cut grass silage (Keady *et al.*, 2012) in agreement with our results for cost of maize and grass silages. In the present study, both treatments had no effect neither on milk production nor milk composition. The absence of any difference in milk yield might be explained by the adequate net energy intake of the cows, which is further confirmed by the absence of variation in live body weight.

Grazing has been proposed as an essential strategy for the efficient use of pastoral resources, which are abundant in wet temperate areas. In these climatic conditions, grazing is allowed all year round. This fact allows savings in the cost of feed in the dairy farms, which could provide an increase in the profitability. However, in this experiment, grazing occurred only for 6 hours daily as a result of drought that year, since rainfall was almost one-third less than the average of historical records (Infomet, 2015). Despite this, the intake from grazing reached over 26% of the total DMI, and only accounted for 1% of the total feeding costs. The concentrates used, bought off-farm, represented 21% of the total DMI, but account over 66% of the total feeding cost. The concentrate intake per kilogram of milk produced was lower in cows with MnF than ChF treatment. The expenses on concentrate in MnF treatment represent 58 €/t of milk while the ChF treatment spent 64 €/t of milk. The difference between MnF and ChF treatments reflects a saving of 25.3 eurocents in the cost of feed per cow and day, and represents the creation of 21.8 eurocents in added value. Given these conditions, for the average herd with 40 dairy cows grazing, using maize silage produced with organic fertilization in the diet could bring increased incomes of over 3000 € per year.

The higher total DMI in the MnF treatment led to greater daily enteric CH_4 emission than by the ChF fed cows, because of the level of DMI is the main driver on methane emissions in cattle (Bannink *et al.*, 2010). In addition, this was favored by the differences, although not significant, toward a higher grass intake. The pasture contains a high concentration of structural carbohydrates that increase the rumen retention time and affect the fermentation pattern, which results in a greater methanogenic capacity (Janssen, 2010). In both treatments, the enteric CH_4 emissions estimated were higher than the estimated values by Legesse *et al.* (2011) or measured in respiratory chambers by Brask *et al.* (2013). However, the proportion of forage in all these studies was 60% or less. Aguerre *et al.* (2011) studied the effect of forage-to-concentrate ratio in dairy cow diets on GHG emission. Increasing the proportion of forage from 47% to 68% in the diet increased CH_4 emission from 0.538 to 0.648 kg CH_4 per cow and day. In our study, the diets had a 79% forage, and therefore, this could explain our higher estimated GHG emissions. Nitrogen oxide emissions generated by soil management were similar between diets because both chemical and organic fertilizers had equivalent amounts of N and crop residues were similar. On the other hand, N_2O is also produced directly through nitrification and denitrification, and indirectly by the volatilization and leaching of the manure's N. Urinary N is more labile than fecal N and it is considered the main contributor to NH_3 and total N losses. Therefore, it is important to reduce the urinary N losses and/or derive N excretion through the faeces (Hristov, 2013). Our results demonstrate that is possible reducing the

CO_2eq emissions with the use of manure as own source, without lowering the milk production.

On the basis of the results obtained, it could be concluded that using organic fertilization in the studied conditions saves costs of maize crop for silage. The silage produced with this management had higher starch content, reducing 11.3% the intake of concentrate per kilogram of milk in grazing dairy cows, without increasing the voluntary intake of grass. This fact makes significant feed cost savings per cow and day, increasing profit margins. The use of maize silage grown with organic fertilization does not alter the milk yield and raw composition. The results show that using organic fertilization on maize culture is possible reducing the GHG emissions with regard to chemical fertilization without lowering the production.

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