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Anaerobic digestion and milking frequency as mitigation strategies of the environmental burden in the milk production system

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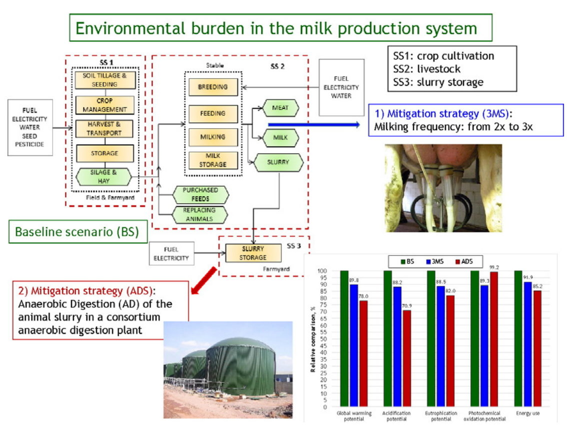
HIGHLIGHTS

- The environmental impact of milk in Italy was estimated through Life Cycle Assessment.
- Livestock and crop production had a great effect on environmental impact of dairy farms.
- Third milking and anaerobic digestion (AD) were assessed as mitigation strategies.
- AD strongly reduces acidification, global warming, eutrophication and energy use.
- Environmental benefits were found increasing milking frequency from 2 to 3 per day.

GRAPHICAL ABSTRACT



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ABSTRACT

The aim of the study was to assess, through a cradle to farm gate Life Cycle Assessment, different mitigation strategies of the potential environmental impacts of milk production at farm level. The environmental performances of a conventional intensive dairy farm in Northern Italy (baseline scenario) were compared with the results obtained: from the introduction of the third daily milking and from the adoption of anaerobic digestion (AD) of animal slurry in a consortium AD plant. The AD plant, fed only with animal slurries coming also from nearby farms. Key parameters concerning on-farm activities (forage production, energy consumptions, agricultural machines maintenance, manure and livestock management), off-farm activities (production of fertilizers, pesticides, bedding materials, purchased forages, purchased concentrate feed, replacement animals, agricultural machines manufacturing, electricity, fuel) and transportation were considered. The functional unit was 1 kg fat and protein corrected milk (FPCM) leaving the farm gate. The selected environmental impact categories were: global warming potential, acidification, eutrophication, photochemical oxidation and non-renewable energy use. The production of 1 kg of FPCM caused, in the baseline scenario, the following environmental impact potentials: global warming potential 1.12 kg CO_2 eq; acidification 15.5 g SO_2 eq; eutrophication 5.62 g PO_4^{3-} eq; photochemical oxidation 0.87 g C_2H_4 eq/kg FPCM; energy use 4.66 MJ eq. The increase of milking frequency improved environmental performances for all impact categories in comparison with the baseline scenario; in particular acidification and eutrophication potentials showed the largest reductions (−11 and −12%, respectively). In anaerobic

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digestion scenario, compared to the baseline one, most of the impact potentials were strongly reduced. In particular the most important advantages were in terms of acidification (−29%), global warming (−22%) and eutrophication potential (−18%). The AD of cow slurry is confirmed as an effective strategy to mitigate the environmental impact of milk production at farm level.

1. Introduction

The contribution to the global human-induced greenhouse gas (GHG) emissions from milk production has been recently estimated at about 3% (Gerber et al., 2013).

The European dairy farming is currently facing numerous changes; in particular a progressive intensification process has largely increased crop and animal productivity with the introduction of new technologies, process specialization, large scale mechanization, and increased use of external inputs (Gaudino et al., 2014). Intensification of milk production requests an increase of the use of external input in the dairy farm with a consequence concentration of gas emissions and nutrient flow in the environment at local scale. Moreover, new green payments across farms within the latest Common Agricultural Policy reform and the removal of the European Union (EU) milk quota system in 2015 are expected to lead to further changes for EU dairy farmers (Del Prado et al., 2013).

A number of strategies for mitigating the environmental impact of milk production at farm level have been proposed. Maximizing production efficiency at animal level seems to produce the best results in terms of environmental impact (Kristensen et al., 2011; De Boer et al., 2011; Rotz et al., 2010), particularly by: increasing of genetic merit of the herd (O'Brien et al., 2014); administering BSt (Rotz et al., 2010); reducing the replacement rate (Vellinga et al., 2011); improving fertility and health parameters (De Boer et al., 2011); finding the optimal combination between milk yield and replacement rate (Zehetmeier et al., 2014); increasing efficiency of feed conversion through balanced and precise feeding and selection of high producing cows (Guerci et al., 2013); improving ensiling (Bacenetti and Fusi, 2015).

According to Weiske et al. (2006), besides improving production efficiency, other promising actions for mitigating the impacts of dairy farms are: 1) frequent removal of slurry and use of scraping systems; 2) improved slurry storage and 3) biogas production by anaerobic digestion (AD).Traditionally, in Italy, the intensive dairy farms use to milk cows twice a day. The introduction of the third milking, with the consequent increase of milk production (Erdman and Varner, 1995; Smith et al. (2002), seems to be an interesting strategy in order to increase the profitability of dairy farms but can also have positive effects in reducing the environmental impact per milk unit.

On the other hand, anaerobic digestion (AD) of animal slurry has been recognized by several studies (Bacenetti et al., 2013; Lijó et al., 2014a; Lijó et al., 2014b) as a suitable and effective solution to produce energy and to reduce the environmental impact (in particular GHG emissions) of livestock activities. In Italy, thanks to strong public incentives for electricity (EE) generation from renewable sources, there are about 1150 AD plants (Negri et al., 2014a). Although most of these plants are fed with cereal silages (González-García et al., 2013; Bacenetti et al., 2014), after the revision of the subsidies framework (Ministero Sviluppo Economico, 2012) the interest about small AD plants (electric power < 300 kW) fed with animal slurries is increasing (Negri et al., 2014b).

Nowadays, Life Cycle Assessment (LCA) is also accepted and used for the evaluation of agricultural activities, where it can be applied to: 1) detect the environmental hotspots (processes or activities responsible for the main share of the environmental impacts) and, 2) to compare different processes or different technical solutions that can be implemented in the same process (Harada et al., 2007; González-García et al., 2013; Bacenetti et al., 2013; Bacenetti et al., 2015b). The European Commission states that "LCAs provide the best framework for assessing the potential environmental impacts of products currently available" (CEC, 2003).

The aim of the study was to assess through an attributional LCA approach the potential environmental impacts of milk production at farm level under different mitigation strategies. In particular the environmental performances of a conventional intensive dairy farm in Northern Italy (baseline scenario) were compared with the results obtained: 1) from the introduction of the third daily milking 2) from the adoption of anaerobic digestion of animal slurry thanks to a consortium plant.

2. Materials and methods

2.1. Farm description

The impact potential of milk production in the two strategies was evaluated with a Life Cycle Assessment (LCA) approach using as a model an intensive dairy farm located in the Po Valley area (Northern Italy), and, more precisely, on the experimental farm of the University of Milan at Landriano (PV). The herd is composed by 85 lactating cows, 25 dry cows, 64 heifers (between 6 and 24 months) and 18 female calves.

The global farm agricultural area is 50 ha; all the surface can be irrigated.

The local climate is characterized by an average annual temperature of 12.7 °C, and the rainfall is mainly concentrated in autumn and spring (average annual precipitation 745 mm).

This study has been carried out from a cradle-to-farm gate perspective. The LCA model was carried out by including three subsystems: 1) crop cultivation, 2) livestock and 3) slurry storage.

The subsystem 1 involves the cultivation of maize (1 hybrid for whole plant silage production), winter cereals (mix of wheat and triticale), Italian ryegrass and sorghum. The subsystem 1 could be considered as upstream process, as defined by PCR rules for raw milk (V 1.01, 2013). Table 1 reports more details about the use of the agricultural area in the dairy farm under investigation. Part of the farm agricultural land was utilized in a double cropping system (maize silage and Italian ryegrass hay).

For all the crops, the cultivation practices were divided in different phases: 1) soil preparation, 2) soil tillage and seeding, 3) crop growth, 4) product harvesting, 5) field-to-farm transport and 6) storage. Cultivation practices hugely varied among the different crops in particular with regards to pesticide application, harvest operation and farm storage.

The Subsystem 2 (core processes, PCR, 2013) involves livestock management and feeding and milking procedures. The herd was composed mostly by Italian Friesian cows. Animals were kept in loose

Table 1
Utilization of the agricultural area in the dairy farm.

Cropping system	Crop	Area (ha)	Product
Single crop	Maize hybrid 700	18.5	Whole plant silage
Single crop	Maize hybrid 700	12.0	Ear silage
Double crop	Maize hybrid 500 Italian ryegrass	4.0	Whole plant silage Hay
Double crop	Maize hybrid 500 Italian ryegrass	4.5	Ear silage Hay
Single crop	Winter cereals	5.0	Whole plant silage
Single crop	Sorghum	6.0	Whole plant silage