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Research article

Greenhouse gas balance of mountain dairy farms as affected by grassland carbon sequestration

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ABSTRACT

Recent studies on milk production have often focused on environmental impacts analysed using the Life Cycle Assessment (LCA) approach. In grassland-based livestock systems, soil carbon sequestration might be a potential sink to mitigate greenhouse gas (GHG) balance. Nevertheless, there is no commonly shared methodology. In this work, the GHG emissions of small-scale mountain dairy farms were assessed using the LCA approach. Two functional units, kg of Fat and Protein Corrected Milk (FPCM) and Utilizable Agricultural Land (UAL), and two different emissions allocations methods, no allocation and physical allocation, which accounts for the co-product beef, were considered. Two groups of small-scale dairy farms were identified based on the Livestock Units (LU) reared: <30 LU (LLU) and >30 LU (HLU). Before considering soil carbon sequestration in LCA, performing no allocation methods, LLU farms tended to have higher GHG emission than HLU farms per kg of FPCM (1.94 vs. 1.59 kg CO_2-eq/kg FPCM, $P \leq 0.10$), whereas the situation was reversed upon considering the m^2 of UAL as a functional unit (0.29 vs. 0.89 kg CO_2-eq/m^2, $P \leq 0.05$). Conversely, considering physical allocation, the difference between the two groups became less noticeable. When the contribution from soil carbon sequestration was included in the LCA and no allocation method was performed, LLU farms registered higher values of GHG emission per kg of FPCM than HLU farms (1.38 vs. 1.10 kg CO_2-eq/kg FPCM, $P \leq 0.05$), and the situation was likewise reversed in this case upon considering the m^2 of UAL as a functional unit (0.22 vs. 0.73 kg CO_2-eq/m^2, $P \leq 0.05$). To highlight how the presence of grasslands is crucial for the carbon footprint of small-scale farms, this study also applied a simulation for increasing the forage self-sufficiency of farms to 100%. In this case, an average reduction of GHG emission per kg of FPCM of farms was estimated both with no allocation and with physical allocation, reaching 27.0% and 28.8%, respectively.

1. Introduction

Recent scientific literature have often assessed carbon footprint of dairy production systems using the Life Cycle Assessment (LCA) approach. LCA is a method of evaluating and quantifying the environmental impacts associated with a product/process/activity throughout the whole life cycle, from raw material to the end of life ("from the cradle to the grave"), and it is governed by ISO 14040-3. However, the application of LCA to dairy farms remains controversial (Flysjö et al., 2012; Pirlo, 2012), and there is no commonly accepted approach to accounting for soil carbon sequestration (Batalla et al., 2015). Carbon sequestration is the process of removing carbon from the atmosphere and depositing it temporarily in a reservoir such as the soil. The time of carbon storage in agricultural soil depends on both abiotic and biotic environmental factors, as well as the types of crops and the land management actions. The magnitude of these fluxes is strongly influenced by the climate and can provide feedback on the climate system (Davidson and Janssens, 2006; IPCC, 2007b). Moreover, grassland soil carbon sequestration could be seen as an important mitigating action (Soussana et al., 2010).

The application of LCA to dairy farms usually does not consider the multifunctional character of livestock systems, and final environmental emissions are apportioned only to the milk and the co-product meat. In this way, when considering the LCA approach for assessing greenhouse gas (GHG) emissions, the small-scale mountain dairy farms are in a disadvantaged position with respect to intensive farms because of their limited productivity (Gerber et al., 2011). However, on the other hand, small-scale dairy farms are characterized by the high presence of grassland, low

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presence of arable crops, low extra-farm inputs, and a lower density of animals per hectare (Battaglini et al., 2014). The presence of grassland also has a positive effect on energy consumption because it increases self-sufficiency in feed, reducing the impact of the production and transport of purchased feed (Guerci et al., 2013), and reduces the field operations required for tillage, planting, and harvesting in comparison with arable crops (Belflower et al., 2012). Moreover, small-scale dairy farms should be considered multi-functional systems (OECD, 2001) that produce milk and meat and, especially in less favoured areas, contribute positively to other control functions, providing a wide range of ecosystem services (ES) (Battaglini et al., 2014; Bernués et al., 2014; Kiefer et al., 2015; Salvador et al., 2016).

To our knowledge, very few studies about the assessment of GHG emissions in small-scale dairy farms are available, and no one has focused on the role of grassland (meadow, for hay production, and pasture, directly grazed) on GHG balance.

The aim of this study is to assess the effect of grassland carbon sequestration accounting on the climate change impact of small-scale dairy farms in the Italian Alps.

2. Materials and methods

2.1. Data collection and sample description

For this study, thirty-four mountain farms, classified as small-scale dairy farms (EFSA, 2015) and representative of the Italian Alpine region, were considered. In particular, these farms were located over 600 m in altitude, were handled by family members, had a high forage self-sufficiency (min 46.3%), and held dual-purpose breeds (mainly Rendena and Italian Simmental). The size of the herd varied considerably, and the average Livestock Units (LU) reared were 38.8; calving was concentrated in autumn, and the total farmland was on average 50.2 ha. They did not manage arable crops and used meadows, for the production of hay offered to animals during the winter period, and pastures, directly grazed by the animals during summertime (at least for heifers, min 60 days/year). More details are reported in Table 1.

Within the small-scale dairy farms considered, two groups of 17 farms each were identified on the basis of the LU reared. One group reared fewer than 30 LU (LLU), while the other group reared more than 30 LU (HLU). The threshold chosen for discriminating the two groups is the limit identified by the Italian Ministerial Decree 18354/2009 regarding organic farms (Reg. UE 834/2007; Reg. UE 889/2008) under which small farms are allowed to rear animals in tie stall.

To obtain a detailed inventory, the farms were analysed by field investigation and through a farmer questionnaire, as well as by consultations with local associations. The Italian livestock breeders association and dairies provided information about the amount of milk and its protein and fat composition. The questionnaire covered farm structure, management, summer grazing period, and input and output mass flow (forage, concentrate feed, milk, meat, fertilizer, and pesticides) data.

Table 1
Main characteristics of 34 small-scale dairy farms sampled in Italian Alps.

	Mean	SE
Total farm land, ha	50.2	11.23
Highland pasture, ha	33.5	10.04
Permanent grassland, ha	16.7	1.81
Herd size, LU	38.8	7.6
Grazing days per cow, n	98	10.1
Grazing days per heifer, n	127	6.0
Forage self-sufficiency, %	79.7	3.06
Milk yield, kg FPCM/cow/year	4621	181.3
Animals sold, kg LW/farm/year	3708	577.6

SE: Standard Error; LU: Livestock Units; FPCM: Fat and Protein Corrected Milk; LW: Live Weight.

2.2. Description of methodology for calculating the carbon footprint and impact category

Carbon footprint of the sampled farms were calculated using the LCA approach (Guinèe et al., 2001), and following the indications of the Intergovernmental Panel on Climate Change (IPCC, 2006a, 2006b). Climate change was selected as impact category. The global warming potentials (GWP) computed according to the CO_2 equivalent factors in a 100 year time horizon were 1 kg CH_4 = 25 kg CO_2-eq, and 1 kg N_2O = 298 CO_2-eq (IPCC, 2007a).

2.2.1. Functional unit and system boundaries

In this study, two functional units were used: kg of Fat and Protein Corrected Milk (FPCM), FPCM (kg) = kg of milk × (0.337 + 0.116 × % fat + 0.060 × % protein) (Gerber et al., 2010) and m^2 of Utilizable Agricultural Land (UAL).

Small-scale farms were analysed in a "cradle to farm-gate" LCA approach which implies that GHG emissions were assessed for all processes involved until the milk leaves the farm, excluding transport or raw milk processing. All the processes related to the on-farm activity (i.e. animals rations, manure storage, cropping system and fuel consumption) and related emissions were taken into account. Emissions from off-farm activities were also estimated. Farm buildings and machineries, medicines, and other minor stables supplies were excluded from the assessment. Fig. 1 illustrates the system boundaries of this study.

2.2.2. Calculation of emissions and allocation method

Methane (CH_4) emissions from enteric fermentation and manure management were estimated according to Tier 2 of IPCC (2006a) guidelines. CH_4 from enteric fermentation, based on dry matter (DM) intake of the herd, was calculated by using a Y_m of 6% for lactating cows and 4% for young cattle (ISPRA, 2008; Pirlo and Carè, 2013). Management of manure was the same for the two groups of farms, and CH_4 conversion factors (MCF) used for manure emission were 2% for solid storage and 1% for dung deposition during grazing time, with an annual average temperature of 10 °C (IPCC, 2006a).

Direct nitrous oxide (N_2O) emissions at storage level were also estimated as proposed by Tier 2 of the IPCC (2006a) and the count was based on excretion of nitrogen (N), estimated as the DM intake and the N content of the diet. The protein of indoor diet was calculated on the basis of data provided by commercial feed producers for the purchased concentrates and on the basis of laboratory analysis for farms concentrate and forage. Analyses to estimate N content were performed according to Kjeldahl method (AOAC, 2000) and crude protein content was calculated (%N × 6.25). The total contribution of grazing to the diet resulted from nutrient requirements of cattle (NRC, 2001) and resources grazed were included in the diet depending on the period spent on high pastures. Emission factors used for direct N_2O was 0.005. The Tier 1 (IPCC, 2006b) was applied for estimating direct and indirect N_2O emissions at field level and for N_2O emissions produced from leaching and runoff. Direct N_2O emissions at field level were calculated applying the emissions factors of 0.01 for managed soils (meadows) and 0.02 for grazed soils (IPCC, 2006b). Direct deposition of dung and urine on pasture was determined computing the average time spent outdoors by the animals. Indirect N_2O emissions at field level were calculated applying the following emissions factors: 0.01 N_2O-N/kg of N volatilized (IPCC, 2006b); 0.092 for