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## Environmental efficiency and carbon sequestration potential of organic vs. conventional simmental dairy farming systems in Mountain regions: a case study

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### ABSTRACT

Numerous studies have investigated the environmental impacts of dairy cattle farming systems using the Life Cycle Assessment (LCA) methodology. However, considering additional related factors can provide a broader perspective and more comprehensive contextualisation of the results. Net food production is a crucial aspect that adds valuable insights to the discussion on sustainable farming practices. Moreover, few studies have focused on mountain dairy farming systems, which differ significantly in structure and management from large-scale dairy operations in the lowlands. This study aims to provide a comprehensive comparison between conventionally and organically managed mountain dairy farms, specifically focusing on dual-purpose Simmental cattle. Six impact categories, Global Warming Potential (GWP<sub>100</sub>), Marine Eutrophication Potential (ME), Terrestrial Acidification Potential (TA), Land Use (LU), and Water Use (WU), were quantified *via* the LCA approach and attributed to one kilogram of Energy Corrected Milk (ECM) and one m<sup>2</sup> of on-farm agricultural area. To determine the individual farm's efficiency to provide human edible food, two additional indicators were calculated: milk yield deriving from roughage and net protein provision, based on the amount of human edible protein in the animal diet vs. the amount of human edible protein inside the milk. Further, carbon sequestration by permanent grassland was calculated for each farm. Results showed lower impacts of the organically managed farms (ORG group) for the categories ME (0.0009 vs. 0.0017 kg N eq) and WU (0.02 vs. 0.08 m<sup>3</sup> kg ECM<sup>-1</sup>), while no significant differences could be found for GWP<sub>100</sub> and TA, and the conventional farms (CON group) were more efficient in LU (0.97 vs. 1.54 m<sup>2</sup>a crop eq). In the case of net food production, the CON group showed an overall higher efficiency (0.023 vs. -0.016 NP kg ECM<sup>-1</sup>), mainly due to maize silage input. No significant difference was found in the C sequestration of permanent grassland between the two groups. This study analysed diverse mountain dairy farms using a single cattle breed, focusing on management, environmental impact, food efficiency, and carbon sequestration. Enhancing sustainability in these systems requires considering not only emissions but also their role in converting non-edible feed into food, maintaining low local environmental impact, preserving grasslands, and supporting ecosystem services.

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### Introduction

Recent scientific assessments, in particular the Sixth Assessment Report (AR6) released by the Intergovernmental Panel on Climate Change (IPCC 2023a), have provided robust evidence that human-induced greenhouse gas (GHG) emissions are the principal driver of global climate change. Anthropogenic activities have led to a documented rise in global surface temperature of approximately 1.1 °C above the 1850–1900 baseline,

observed over the period from 2011 to 2020. The upward trend in global GHG emissions continues, largely driven by both historical and ongoing contributions linked to unsustainable energy use, land management practices, consumption and production patterns, and lifestyle choices at individual, national, and regional levels. In 2019, total net anthropogenic GHG emissions were estimated at 59 ± 6.6 gigatons (Gt) of CO<sub>2</sub> equivalent, reflecting an increase of roughly 12% (6.5 Gt CO<sub>2</sub>-

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eq) since 2010 and a 54% rise (21 Gt CO<sub>2</sub>-eq) compared to 1990 levels (IPCC 2023a). Emissions from the Agriculture, Forestry, and Other Land Use (AFOLU) sector account for approximately 13 Gt CO<sub>2</sub>-eq, or 22% of total net anthropogenic emissions, with Europe contributing around 3% to this total. Within this sector, livestock, particularly ruminant species, plays a significant role, contributing about 26% of AFOLU emissions primarily through enteric methane production and manure management practices (Dhakai et al. 2022). In terms of CO<sub>2</sub> emissions, agriculture, and livestock farming in particular, are one of the strongest emitters on a global level (IPCC 2023b). According to the Intergovernmental Panel on Climate Change (IPCC), the main GHG emissions attributed to the agricultural sector are nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>), that is mainly produced by ruminants. In ruminants, CH<sub>4</sub> mainly originates from microbial fermentation of cellulosic feed material inside the rumen, while a minor percentage is formed in the intestine and during the decomposition of manure (Zanon et al. 2025a). Enteric CH<sub>4</sub> emissions were found to increase with diets containing a high percentage of fibre, while high starch diets, mainly composed of a high percentage of concentrates, decrease CH<sub>4</sub> emissions (Rotz 2020). Further, more intensive farming systems characterised by high-concentration inputs were found to best meet global food demands while reducing the environmental impact per unit of output at the same time (Wilkinson 2011; Gerbens-Leenes et al. 2013; Herrero and Thornton 2013; Zanon et al. 2023). However, the increasing use of human edible food as livestock feedstuff increased the competition for arable land and cereals between livestock and human demands. Since ruminants have the ability to convert human-inedible grassland to precious human-edible food that is high in energy and protein, it appears that an efficient exploitation of roughage is more reasonable (Zanon et al. 2025b). Global dairy milk production has risen by 10% over the past decade, with projections indicating the continuation of this upward trend (FAO 2022). Meeting the growing demand for milk necessitates improvements in productivity while ensuring environmental sustainability. Key environmental challenges associated with milk production systems include emissions to air and water, which contribute to climate change and the eutrophication of aquatic ecosystems, as well as the consumption of critical resources such as energy, water, and land. Achieving net-zero GHG emissions necessitates robust accounting methods, the establishment of representative baselines that integrate environmental variables, and the assessment of how alternative management practices influence GHG emissions. Monitoring these reductions presents an even

greater challenge for organic dairy farms, which have been largely underrepresented in carbon accounting studies and tools in the European Union (EU), also in Italy (Hietala et al. 2015). The growing demand for organic products further underscores the need to conduct life cycle assessments (LCAs) of organic dairy farms (Li 2025). The Farm to Fork strategy, a key component of the European Green Deal, seeks to drive the transition towards a sustainable food system that is equitable, health-conscious, and environmentally sustainable (Alrhoun et al. 2025). One proposed approach to achieving this transition is the expansion of organic farming to cover 25% of the EU's agricultural area by 2030 (European Commission 2021). However, as of now, only 9.9% of the utilised agricultural area in the EU is managed organically (Willer and Schlatter 2023). Consequently, attaining the 25% target would require a significant conversion of farmland from conventional to organic production methods in the coming years (Kremmydas et al. 2025). Organic systems usually have greater use of permanent pasture and grassland compared to conventional systems. Pastures possess a more extensive root system compared to other crops, enabling greater carbon sequestration in the soil; this process can help reduce the carbon intensity of milk production by offsetting GHG (Holly et al. 2019; Ghosh et al. 2020). However, few studies keep carbon sequestered from pastures within the account in the dairy sector (Salvador et al. 2017; Sabia et al. 2020), and no studies have been identified by us in dairy cow organic systems.

Therefore, the aim of this study was to compare environmental impacts through LCA approach, as well as feed efficiency of organically managed mountain dairy cattle farms with 100% seasonal pasture access and a high share of on-farm feed production, as well as limited amounts of concentrate feed in the diet, with conventionally managed dairy farms with no or neglectable pasture access during summer, as well as higher concentrate input and to explore potential mitigation strategies through carbon sequestration storage by permanent pastures.

## Materials and methods

### Study area

South Tyrol is an Alpine province, located in Northern Italy, bordering Austria and Switzerland. In terms of area, grassland is the most important forage source, where 61,332 hectares of grassland are mown to produce feed for livestock and 127,216 hectares are grazed as mountain pastures (Autonome Provinz Bozen 2021). With an overall of 4,105 farms of 15 dairy

cows, dairy cattle farming is the most relevant livestock sector in South Tyrol (Südtiroler Milch, Milch 2023). With overall 30%, Simmental and Brown Swiss are the most common dairy cattle breeds, while Holstein Frisian make up to roughly 20% (Zanon et al. 2020). The residual 20% are composed of traditional cattle breeds, such as Alpine Grey and Pinzgauer (Agrar- and Forstbericht 2023).

### Selection and classification of farms

In total, 30 mountain dairy farms were visited between May and October 2023, and primary data were collected directly during farm visits using a questionnaire. The farmer interview consisted of a detailed questionnaire based on basic agricultural production data, farm structure, and farm management information, with a focus on all farm inputs and outputs. The complete questionnaire is available as a supplement under the link 10.17632/wx364686p8.1. Farmers voluntarily participated in barn visits and interviews, lasting 1.5-2 h per farm in total. Table 1 illustrates the main features of these farms. The farms were selected in cooperation with the South Tyrolean breeders' associations. The criteria for the selection were the uniformity of the herd, being composed of preferably only purebred dual-purpose Simmental cattle, which is the most used cattle breed in the dairy farms in the study region (Flach et al. 2021). Additionally, the farms should undergo continuous milk quality testing by the South Tyrolean Dairy Association. Participation was voluntary. Out of the potential mountain dairy farms, in total 15 organically managed Simmental cattle farms (ORG), certified according to the EU-regulations on organic production (EUR-Lex 2018) and following the hay-milk production scheme with reduced concentrate (max. 25% in the annual feed ratio) and no silage

feeding (EUR-Lex 2018), were chosen randomly. For the conventionally managed farms (CON), the selection criteria were an average milk yield of above 8,000 kg of milk per cow and year, which indicates besides farm efficiency, also an intensive feeding system. Out of the farms that met these conditions, 15 farms were chosen by chance. The average number of animals on the farms is  $17.5 \pm 5.2$  SD and  $16.1 \pm 7.9$  SD for the CON and the ORG farms, respectively (Table 1). Besides the restricted amount of concentrates due to the production of hay-milk, seasonal pasture access is guaranteed by organic farms, based on the regulation on organic production, issued by the European Union (EUR-Lex 2018), while on the surveyed conventional farms, no or negligible pasture access was implied in the management, apart from autumn pasturing with negligible herbage feed intake. The livestock unit (LSU) is a reference unit which facilitates the aggregation of livestock from various species and ages as per convention, *via* the use of specific coefficients established initially on the basis of the nutritional or feed requirements of each type of animal. In detail, 1 LSU is equivalent to an adult cow milk producing at least 3,000 kg of milk per year (EUROSTAT 2020). The main characteristics of the percentage composition of the feed for both systems under study are shown in Table 2. In terms of fertiliser, in both production systems, only organic fertilisers (slurry, manure) and no synthetic fertilisers were used. These farms are no direct example of all mountain dairy farms, but rather represent a wide range of different farming systems, mainly caused by the high geographic heterogeneity in mountain areas. Especially for the organically managed farms, a certain percentage of animals were not purebred Simmental cattle. Within the Simmental cattle herds of some ORG farms, single animals were crossbred with Red Holstein.

**Table 1.** Average values for farm characteristics of conventionally and organically managed farms and standard deviation (SD).

Farm characteristic	CON (n = 15)					ORG (n = 15)				
	Mean	Median	Min	Max	SD	Mean	Median	Min	Max	SD
Elevation (m a.s.l.)	1,148	1,117	836	1,450	189	1,218	1,302	650	1,500	246
No dairy cows	17.5	17.0	10.0	30.0	5.2	16.1	16.0	3.0	36.0	7.9
No calves (< 6 months)	3.7	4.0	0.0	10.0	2.5	2.4	2.0	0.0	6.0	1.7
No calves (6–24 months)	4.7	5.0	0.0	10.0	2.9	4.0	3.0	0.0	10.0	2.8
No heifers	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	1.0	0.4
No bulls	0.3	0.0	0.0	3.0	0.9	0.1	0.0	0.0	1.0	0.4
Permanent grassland (ha)	12.4	11.8	5.1	20.5	4.9	12.4	13.0	2.6	24.0	5.3
Arable land (ha)	0.1	0.0	0.0	1.0	0.3	0.0	0.0	0.0	0.6	0.2
Grassland yields (kg DM * ha <sup>-1</sup> ) including pasturage	5,180	5,015	2,931	7,000	1,567	5,203	5,250	2,623	6,446	961
Number of cuts	3.14	–	1	6	1.08	2.0	–	1	3	0.72
Stocking rate (LSU ha <sup>-1</sup> )	1.53	1.60	0.86	2.10	0.37	1.31	1.30	0.85	1.66	0.28
Days of pasture dairy cows (days year <sup>-1</sup> )	25.3	30	0	60	25.7	201.3	120	280	200	36.9
Milk yield (kg ECM * animal * year <sup>-1</sup> )	9,505	9,471	8,031	10,817	912	6,540	6,611	3,454	9,294	1,336

m.a.s.l.= metres above sea level, DM = dry matter, ECM = Energy corrected milk.

**Table 2.** Average values and standard deviation (SD) of feeding farm characteristics of conventionally and organically managed farms on dry matters basis.

Feeding regime	CON (n = 15)				ORG (n = 15)			
	Summer		Winter		Summer		Winter	
	Average	SD	Average	SD	Average	SD	Average	SD
Pasture feed	0%	0%	0%	0%	16%	4%	0%	0%
Hay	39%	19%	37%	19%	64%	6%	80%	5%
Grass silage	24%	16%	25%	14%	0%	0%	0%	0%
Maize silage	7%	9%	8%	9%	0%	0%	0%	0%
Concentrates	29%	6%	28%	6%	19%	6%	19%	5%
Other diet components*	2%	3%	2%	6%	0%	0%	0%	0%

\*Other diet components = wheat bran, brewer's grains, straw, propylene glycol.

## Life cycle assessment methodology

### Definition of goal and scope, functional units

Environmental impacts were calculated per kg of ECM, in order to compare two dairy farming systems based on dual-purpose Simmental cattle. A cradle-to-farm gate approach was employed for the Life Cycle Assessment, while no allocation method was chosen for calves and breeding since all male calves are sold at birth and do not remain within the system. The assessment of Mid-Point impacts was conducted using the commercial software openLCA 2.0.1, employing the Agribalyse database v. 3.0.1 and the ReCiPe Midpoint (H) method (Huijbregts et al. 2017). Impact assessment considered was Global warming potential (GWP<sub>100</sub>, kg CO<sub>2</sub> eq), Marine eutrophication (ME, kg N eq), Terrestrial acidification (TA, kg SO<sub>2</sub> eq), Land use (LU, m<sup>2</sup> year crop eq) and Water Use (WU m<sup>3</sup>). As recommended by the International Dairy Federation (IDF 2022), two functional units (FUs) were utilised:

- I. kg of ECM
- II. m<sup>2</sup> of farm area

Methodological choices were made according to the ISO 14040 and ISO 14044.

### Emission calculation

Total emissions for all farms in the study were calculated. Specifically, the methodology outlined by the Intergovernmental Panel on Climate Change (IPCC 2019) was applied to examine the relationship between gross energy intake (GEI) and emissions from enteric fermentation. GEI was calculated according to the equation provided by IPCC (2019), as described in the literature; all equations used are shown in Table A1. In detail, CH<sub>4</sub> emissions originating from enteric fermentation, manure storage, and direct deposition on grasslands were estimated using the Tier 2 equation recommended by IPCC (2019). For this,

a methane conversion factor (Y<sub>m</sub>) of 4% was used for fattening cattle, and 6.5% for adult cows and bulls. CH<sub>4</sub> emissions from manure volatile solids (VS) were determined to be 3.9 kg per animal per day, with a maximum methane production potential of 0.1 m<sup>3</sup>/kg VS. The methane conversion factor (MCF) was set at 27 for pit storage and 1.5 for pasture (Table A1). Direct and indirect N<sub>2</sub>O emissions from grazing were calculated using the IPCC equation. Nitrous oxide emissions from manure were estimated based on total nitrogen excretion, using a country-specific emission factor of 0.02 kg N-N<sub>2</sub>O/kg of excreted N for Italy (Romano et al. 2023). For direct nitrogen deposition on soil, an emission factor of 0.0125 kg N-N<sub>2</sub>O/kg N was applied (Romano et al. 2023). Indirect N<sub>2</sub>O emissions were assessed based on IPCC (2019) guidelines, which take into account nitrate leaching, runoff, and the re-deposition of volatilised nitrogen onto soil and water surfaces. An emission factor of 0.01 kg N<sub>2</sub>O-N/kg N was used for indirect atmospheric deposition, while a value of 0.025 kg N-N<sub>2</sub>O/kg N was used for nitrate leaching and runoff, based on the Italian-specific emission factor (Romano et al. 2023). Carbon dioxide (CO<sub>2</sub>) emissions from energy consumption were estimated by considering both direct emissions from fossil fuel combustion and indirect emissions from electricity use. Diesel consumption was measured in litres, and electricity use in kilowatt-hours (kWh) for various farming activities. Following Romano et al. (2023), a diesel density of 0.85 kg per litre and an emission factor of 3.14 kg CO<sub>2</sub> eq/kg of diesel burned were used to estimate CO<sub>2</sub> emissions. For electricity, an Italian-specific emission factor of 0.40 kg CO<sub>2</sub> eq/kWh was applied (Romano et al. 2023). In the LCA, the characterisation factors used for global warming potential (GWP<sub>100</sub>) were 1, 34, and 298 CO<sub>2</sub> eq for CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O, respectively, as recommended by Huijbregts et al. (2017).

### Milk quality data

Milk quality data for the year 2023 were provided by the South Tyrolean dairy association (Südtiroler Milch, Milch 2023), upon subscription to a specific declaration of consent by each participating farmer, allowing us to use the farm-specific data in an anonymised form. The milk quality was tested at intervals of about 40 days and provided information on daily milk yield, milk composition (fat, protein, casein, lactose, acetone, urea), somatic cell count (SCC), coagulation properties (RTC, a30, k29), and fatty acid profile (Table A2). Milk quantity, as well as information on fat and protein

content, was used to calculate the amounts of energy-corrected milk (ECM) produced per farm. ECM yield was calculated according to Orth (1992) as follows:

$$\begin{aligned} & \text{(Eq. 1)} \\ & \text{Kg ECM yield} = [0.327 \times \text{milk yield} \\ & \text{(kg/d)}] + [12.95 \times \text{milk fat yield} \\ & \text{(kg/d)}] + [7.2 \times \text{milk protein yield (kg/d)}] \end{aligned}$$

As well as for calculating the food-feed conversion efficiency indicators, Roughage-based Milk Yield (RBMV), and net protein provision (NP). For the calculation of the percentage of milk deriving from roughage, Formula (1) of Weiß (2001) was used, where the sum of energy of concentrate amounts is divided by the required energy for milk production (Gruber et al. 2008) and subtracted from the total milk yield. This was done for each farm individually. NP was calculated as the difference between the amount of protein in the milk and the human-edible protein (heP) in the cows' diet. The human edible fraction of feed ingredients was estimated as described by Ertl et al. (2015) and Wilkinson (2011).

### **Estimation of soil organic carbon (SOC)**

The methodology proposed by Petersen et al. (2013), which analyses a 100-year period and suggests that 10% of the total carbon introduced into the soil undergoes sequestration, is recommended. These researchers emphasise the pivotal role of soil in sequestering carbon, presenting it as an effective strategy for mitigating GHG and climate change. This view aligns with other studies, such as those by Soussana et al. (2010), which highlight the importance of soil carbon sequestration in the broader context of land management practices aimed at reducing atmospheric CO<sub>2</sub> concentrations. As indicated by Petersen et al. (2013), estimates of carbon changes in agricultural systems are based on the net carbon fluxes, which reflect the balance between carbon inputs (such as crop residues and manure) and outputs (such as carbon released through respiration and decomposition). The calculation of annual carbon inputs into grasslands includes contributions from both herbage residues and manure, following the methodology detailed by Batalla et al. (2015). These authors suggest that 40% of the total yield is considered above-ground residue, while 16% is attributed to below-ground residues, assuming a carbon content of 45% on a dry matter basis (Equation 2). Their findings imply that, over a 100-year timeframe, 10% of the carbon added to the soil remains sequestered. The estimated amount of

carbon sequestered in grasslands is then deducted from the environmental impact associated with GWP<sub>100</sub>, as outlined by Petersen et al. (2013). To quantify this sequestration, the amount of carbon stored in permanent pastures is converted into CO<sub>2</sub> equivalents using the conversion factor 44/12 before being subtracted from the GWP<sub>100</sub> impact category.

(Equation 2):  $\text{Kg C} \cdot \text{ha}^{-1} = \{[(\text{DM} \times 40\%) + (\text{DM} \times 16\%) \times 45\%]\} \times 10\%$  (Petersen et al. 2013; Sabia et al. 2025)

where

D.M. = Dry Matter

D.M.  $\times$  40% = 40% crop residue aboveground (Soussana et al. 2010)/total crop production

D.M.  $\times$  16% = 16% crop residue belowground (Soussana et al. 2010)/total crop production

### **Statistical analysis**

The data were analysed by general linear models (GLM) with management as a fixed factor and the farm as a random factor, applying the Tukey method. Fulfilment of the assumptions of the analysis of variance (normal distribution of the residuals and homogeneity of the variance) was assessed using the Kolmogorov-Smirnov Test. When an interaction was detected, multiple comparisons were performed using the Least Significant Difference. Differences were considered significant at  $p < 0.05$ . All statistical analyses were conducted using SAS software (SAS Institute Inc., 2024).

## **Results**

### **Farm characteristics**

Overall, a higher variability in terms of farms (Table 1) and of seasonal differences (Table 2) could be found in the ORG group. Despite a lower number of mean cuts per year (3.14 and 2.0 for CON and ORG, respectively), the ORG group shows marginally higher yields per hectare and year (Table 1). With a mean height of 1218 m.a.s.l., ORG farms from our sample were generally located higher than CON farms with 1148 m.a.s.l. It is widely acknowledged that altitudinal factors in alpine environments can influence the productivity per hectare of permanent pastures and permanent grasslands (Peratoner et al. 2010; Klaus et al. 2024); however, the ORG system demonstrates higher productivity. With  $9,505 \pm 912$  SD kg of ECM per animal per year, on average, milk yield was notably higher in the CON group compared to the ORG group, with

6,539 kg  $\pm$  1291 SD. The conventionally managed farm with the lowest MY had average amounts of 8,031, while the farm with the highest MY produced 10,817, on average. The ORG group exhibited values between 3,454 kg and 9,294 kg.

### Environmental implications

For the GWP<sub>100</sub> (kg CO<sub>2</sub> eq.) emissions, no significant differences between the farming systems were found for both FU (Tables 3 and 4) with mean values 1.14  $\pm$  0.180 SD and 1.31  $\pm$  0.229 SD kg CO<sub>2</sub> per kg ECM and 1.24  $\pm$  0.577 SD and 0.99  $\pm$  0.254 SD per m<sup>2</sup> for CON and ORG, respectively. ME were significantly lower for ORG with 0.0009 kg N-eq  $\pm$  0.0003 SD and 0.0007 kg N-eq  $\pm$  0.0002 SD, compared to CON with 0.0017 ( $\pm$ 0.0039 SD) and 0.0017  $\pm$  0.0002 SD kg per kg ECM and per m<sup>2</sup>, respectively ( $p$  < 0.001 and 0.001). TA did not significantly differ between CON with means of 0.0046 kg SO<sub>2</sub>-eq  $\pm$  0.0016 SD and 0.0046 kg SO<sub>2</sub>-eq  $\pm$  0.0009 SD and ORG with 0.0057  $\pm$  0.0022 SD and 0.0041 kg  $\pm$  0.0011 SD, per kg ECM and m<sup>2</sup>, respectively. No significant differences in WU were

found per kg ECM with 0.08 m<sup>3</sup>  $\pm$  0.19 SD and 0.02 m<sup>3</sup>  $\pm$  0.008 SD for CON and ORG, respectively, while for m<sup>2</sup>, differences were significant ( $p$  = 0.037) with CON requiring 0.07 m<sup>3</sup>  $\pm$  0.103 SD and ORG 0.01 m<sup>3</sup>  $\pm$  0.006 SD (Tables 3 and 4). The percentage of RBMY did not significantly differ between CON 47%,  $\pm$  15.6% SD and ORG 56%  $\pm$  9.4% SD. The NP was negative with -0.016 kg per kg ECM in the ORG group  $\pm$  0.007 SD, while CON showed a provision of 0.023 kg per kg ECM  $\pm$  0.015 SD. Differences between the groups were highly significant ( $p$  < 0.0001) (Tables 3 and 4).

### Soil carbon sequestration from grassland

The fraction of CO<sub>2</sub> equivalents fixed by permanent grassland was subtracted from CO<sub>2</sub> equivalents emitted per kg of ECM. For subtracted sequestration via grasslands, results showed a residual GWP<sub>100</sub> of 1.087  $\pm$  0.168 SD and 1.226 kg CO<sub>2</sub>  $\pm$  0.206 SD for CON and ORG, respectively. Differences between the systems were not significant. Mean fraction of fixed CO<sub>2</sub>-equivalents from total CO<sub>2</sub> emissions was 4.92  $\pm$  1.43% SD and 6.21  $\pm$  1.46% for CON and ORG, respectively.

**Table 3.** Mean, median, minimum and maximum values, as well as standard deviation of the impact categories analysed of conventionally (CON) and organically (ORG) managed farm.

Impact category	Unit	CON (n = 15)					ORG (n = 15)				
		Mean	Median	Min	Max	SD	Mean	Median	Min	Max	SD
GWP <sub>100</sub> kg ECM <sup>-1</sup>	kg CO <sub>2</sub> eq	1.14	1.07	0.95	1.64	0.180	1.31	1.28	0.92	1.89	0.229
ME kg ECM <sup>-1</sup>	kg N eq	0.0017	0.0018	0.0007	0.0040	0.0008	0.0009	0.0008	0.0006	0.0017	0.0003
TA kg ECM <sup>-1</sup>	kg SO <sub>2</sub> eq	0.0046	0.0040	0.0028	0.0090	0.0016	0.0057	0.0051	0.0020	0.0099	0.0022
LU kg ECM <sup>-1</sup>	m <sup>2</sup> year crop eq	0.97	0.91	0.70	1.84	0.287	1.54	1.38	0.95	2.71	0.459
WU kg ECM <sup>-1</sup>	m <sup>3</sup> eq	0.08	0.02	0.01	0.72	0.189	0.02	0.01	0.01	0.05	0.008
GWP <sub>100</sub> m <sup>2</sup> -1	kg CO <sub>2</sub> eq	1.24	1.21	0.54	2.29	0.577	0.99	1.00	0.50	1.34	0.254
ME m <sup>2</sup> -1	kg N eq	0.0017	0.0017	0.0005	0.0039	0.0009	0.0007	0.0007	0.0004	0.0011	0.0002
TA m <sup>2</sup> -1	kg SO <sub>2</sub> eq	0.0046	0.0044	0.0019	0.0100	0.0023	0.0041	0.0042	0.0020	0.0063	0.0011
WU m <sup>2</sup> -1	m <sup>3</sup> eq	0.068	0.020	0.007	0.314	0.103	0.013	0.010	0.005	0.029	0.006
RBMY	%	0.47	0.49	0.11	0.74	0.156	0.56	0.52	0.44	0.71	0.094
NP	kg	0.023	0.023	0.000	0.061	0.015	-0.016	-0.017	-0.025	0.004	0.007

GWP<sub>100</sub> = Global Warming Potential, ME = Marine Eutrophication Potential, TA = Terrestrial Acidification Potential, LU = Land Use, WU = Water Use, RBMY = Roughage based milk yield, NP = Net Protein Provision.

**Table 4.** Least square means, p-value and standard error of means (SE of means) of the impact categories of the conventionally (CON) and organically (ORG) managed farms.

Impact category	Unit	Management System		p-value	SE of means
		CON (n = 15)	ORG (n = 15)		
GWP <sub>100</sub> kg ECM <sup>-1</sup>	kg CO <sub>2</sub> eq	1.14	1.31	0.0640	0.0725
ME kg ECM <sup>-1</sup>	kg N eq	0.0017	0.0009	0.0014	0.0002
TA kg ECM <sup>-1</sup>	kg SO <sub>2</sub> eq	0.0046	0.0057	0.1129	0.0007
LU kg ECM <sup>-1</sup>	m <sup>2</sup> a crop eq	0.97	1.54	0.0005	0.1416
WU kg ECM <sup>-1</sup>	m <sup>3</sup>	0.08	0.02	0.0952	0.0450
GWP <sub>100</sub> m <sup>2</sup> -1	kg CO <sub>2</sub> eq	1.24	0.99	0.1817	0.1669
ME m <sup>2</sup> -1	kg N eq	0.0017	0.0007	0.0005	0.0003
TA m <sup>2</sup> -1	kg SO <sub>2</sub> eq	0.0046	0.0041	0.4329	0.0007
WU m <sup>2</sup> -1	m <sup>3</sup>	0.07	0.01	0.0370	0.0248
RBMY	%	0.47	0.56	0.0821	0.0486
NP kg ECM <sup>-1</sup>	kg	0.023	-0.016	<0.0001	0.0046

GWP<sub>100</sub> = Global Warming Potential, ME = Marine Eutrophication Potential, TA = Terrestrial Acidification Potential, LU = Land Use, WU = Water Use, RBMY = Roughage-based milk yield, NP = Net Protein Provision, ECM = Energy Corrected milk.

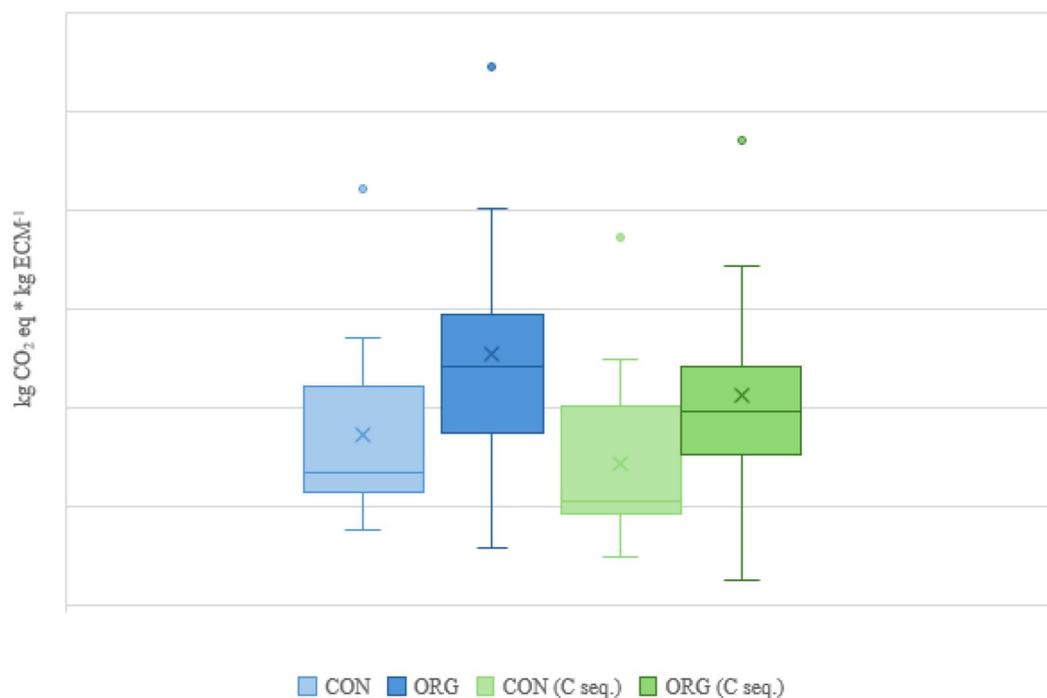
Figure 1 shows CO<sub>2</sub> emissions per kg ECM calculated via OpenLCA (blue) and with carbon sequestration by grasslands included (green) for the CON (light) and ORG group (dark). CO<sub>2</sub> emissions of farms in the ORG group showed a higher scattering, with the overall highest and lowest emissions found within this group, in both scenarios (with and without C sequestration considered), due to the high dispersion of values (Table 5).

## Discussion

### Global warming potential (GWP<sub>100</sub>)

Without any allocation method applied, GHG emissions did not significantly differ between the groups, with marginally higher values per kg of ECM, but marginally lower ones per farm area, for the ORG group. The two systems under investigation, CON and ORG, primarily differ in

terms of regulatory status and certification requirements. While both systems in the South Tyrol region may share several agro-ecological practices—such as the non-use of synthetic fertilisers and a reliance on grass-based feeding strategies the ORG system is formally recognised under European legislation as organic. Specifically, organic farms are regulated by Regulation (EU) 2018/848, which establishes detailed rules regarding organic production, certification procedures, input restrictions, animal welfare standards, and labelling requirements (EUR-Lex 2018). This legal framework ensures compliance with principles of sustainability, environmental protection, and animal health and welfare, and requires periodic inspection and third-party certification (Mie et al. 2017). In contrast, CON farms may adopt similar low-input or extensive practices, but without the obligation to comply with the formal organic certification process and its associated documentation and traceability requirements. Similarly, Berton et al. (2020) observed only small differences in



**Figure 1.** Boxplot of CO<sub>2</sub>-equivalent emissions (GWP<sub>100</sub> \* kg ECM<sup>-1</sup>) of conventionally (CON) and organically (ORG) managed farms ( $n = 15$ ) (left) and boxplot of CO<sub>2</sub>-equivalents (GWP<sub>100</sub> \* kg ECM<sup>-1</sup>) of conventionally and organically managed farms with subtracted values for CO<sub>2</sub>-equivalent sequestration of permanent grassland areas.

**Table 5.** Least square means, p-value and standard error of means (SE of means) of CO<sub>2</sub>-emission values with carbon sequestration of permanent grassland, percentage of CO<sub>2</sub>-equivalents fixed by permanent grassland, and carbon sequestration of permanent grassland for conventionally (CON) and organically (ORG) managed farms.

Category	Unit	Management System		p-value	SE of means
		CON ( $n = 15$ )	ORG ( $n = 15$ )		
CO <sub>2</sub> emissions (GL seq.)	kg CO <sub>2</sub> -eq kg ECM <sup>-1</sup>	1.087	1.226	0.0532	0.0485
CO <sub>2</sub> emissions (GL seq.)	kg CO <sub>2</sub> eq m <sup>2</sup> <sup>-1</sup>	1.181	0.932	0.0621	0.0234
Percentage of GL seq.	%	4.92	6.21	0.0213	0.0037

GL = permanent Grassland; ECM = Energy Corrected milk, seq = Sequestration.

environmental impact values among their investigated mountain dairy farming systems, as both farming systems already produce “organically”, with the difference, however, that CON farms are not certified as organic. Irrespective of this, previous studies showed that organic or low-input farms, due to their general lower productivity, emit higher GHG per unit of product, but are more efficient if land-use related FUs are considered (Sabia et al. 2020; Zanon et al. 2025b). Many studies show that a higher percentage of cereal in the diet leads to higher output and lower enteric fermentation, thus resulting in lower GWP per unit of product (De Vries et al. 2015; Ross et al. 2017). Numbers on GHG emissions per kg ECM are perfectly in line with comparable studies (Salvador et al. 2017; Sabia et al. 2020). GHG emissions per agricultural area ( $\text{m}^2$ ) were significantly higher in our study, which is explainable by the higher stocking rates in our investigated farms compared to Salvador et al. (2017), where stocking rates for organic and conventional farms were 0.8 and 1.9 LSU  $\text{ha}^{-1}$ , respectively.

### **Environmental impacts**

Lower ME for the ORG group agrees with Thomassen et al. (2008), who showed the impact of lower percentages of concentrates on the ME, and O'Brien et al. (2023) nominated synthetic fertiliser as the most important factor, which, in contrast to conventional farming, is not allowed to be used on organic grassland areas. In fact, O'Brien et al. (2023) found that artificial fertiliser, together with organic fertiliser, was responsible for 75–85% of total N equivalents. Similar results were reported by Payen et al. (2020), who found that N fertiliser had the highest impacts on marine ecosystems, while phosphorus (P) loss was found to mainly cause eutrophication in freshwater. In our case, both farming system did not use any synthetic fertiliser. The observed difference in ME might therefore be related to the higher use of concentrates in CON farms, as Flach et al. (2021) observed a higher nutrient efficiency and thus lower N emissions in mountain dairy farming systems, which use less feed concentrates in the ratio. In contrast, manure management and storage, with ammonia ( $\text{NH}_4$ ) being the main agent, was found to play a predominant role for the TA (Chobtang et al. 2016; O'Brien et al. 2023), which has been shown to be less efficient in the ORG group, compared to the CON group, if related to the output product. In the organic diversification scenario of a study conducted by O'Brien et al. (2023), ME, as well as TA, were found to be significantly lower compared to conventional farming, which was shown to

be the case in our study for ME. The  $\text{SO}_2$  emissions (TA) per  $\text{m}^2$ , however, were only marginally lower in ORG, compared to CON, yet implying a higher environmental efficiency related to the agricultural area.

### **Land use**

High LU efficiency is a key component of sustainable livestock systems, as it is associated with lower rates of biodiversity loss (Fischer et al. 2008) and reduced land use change (Bronts et al. 2023). In the present study, ORG exhibited a considerably higher LU per unit of output compared to CON, indicating lower LU efficiency under organic management. While differences in altitude, forage yield potential, or stocking rate could theoretically influence LU (Peratoner et al. 2010). Instead, the most evident and statistically supported driver of the observed differences appears to be milk yield. On average, ORG systems showed lower milk productivity per cow, which directly implies that more land is required to produce an equivalent quantity of milk compared to CON systems. This is consistent with findings from De Vries et al. (2015), who report that lower productivity in organic systems often offsets the environmental benefits associated with reduced input use. Moreover, Nemecek et al. (2011) demonstrated that, across different livestock production systems in Europe, productivity is a dominant factor in determining land use efficiency and other environmental indicators. Similarly, Meier et al. (2015) emphasise that while organic farming reduces pesticide use and fosters biodiversity, it tends to require more land per unit of output due to lower yields. In dairy systems specifically, Smith et al. (2019) showed that LU per litre of milk is significantly lower in high-input, high-output systems, largely due to greater feed conversion efficiency and higher milk yield per animal. Therefore, in this context, the approximately 50% higher LU observed in the ORG group can be plausibly explained by its lower milk yields, which align proportionally with the increased land requirements. This underscores the need to consider productivity metrics alongside input intensity when evaluating the environmental performance of different dairy systems.

### **Water use**

Bronts et al. (2023) report that organic farming systems generally exhibit higher water use than conventional ones—particularly when assessed per unit of product. Our results did not show statistically significant differences in water use per kilogram of ECM

between ORG and CON farms. This suggests that, from a productivity-normalized perspective, both systems perform similarly in terms of water efficiency. When water use is assessed per square metre of agricultural area ( $\text{WU m}^{-2}$ ), ORG farms displayed a statistically significant, albeit numerically modest, reduction in water consumption compared to CON farms. However, this result must be interpreted with caution. Since ORG farms in our sample had lower milk yields per area, the lower  $\text{WU m}^{-2}$  does not imply higher spatial efficiency. On the contrary, lower productivity per unit of land may reduce the overall resource-use efficiency when output is considered. This finding aligns with the observations of Mekonnen and Hoekstra (2012), who emphasise that productivity is a key determinant of water footprint efficiency in livestock systems. As Bronts et al. (2023) and Van Middelaar et al. (2013) highlight, water use efficiency in dairy systems is highly influenced by both feed origin and yield. Therefore, the apparent advantage in WU per land area for ORG systems may largely reflect differences in feed practices and input intensity, rather than greater ecological efficiency.

### **Feed to food conversion efficiency**

Ruminants could play a significant role in the future of livestock farming by reducing the use of potentially human-edible feedstuffs in animal diets, as they convert non-edible resources, such as grasslands, into human-edible food. In particular, this applies to areas that, due to their geographic or climatic conditions, are not suitable for being converted to arable land and efficiently growing human edible plants (FAO 2018; Dumont et al. 2020; Zanon et al. 2023). In this context, the nutritional benefits of ruminant livestock production can be mainly assigned to the production of energy and protein (Nemecek et al. 2011). In the case, the net protein (NP) provision was considered in the calculations, the CON group showed to be more efficient in nutrient supply, while the ORG group showed an average net loss of protein along the conversion process. The NP calculations did not include any allocation method; thus, the only product that was considered within the calculations was the final product of milk. Therefore, since there is a high percentage of protein digested by the animal for maintenance and growth (IPCC 2019), negative values for NP are not directly connected to a loss of protein within the conversion process. Nevertheless, the CON group appears to be more efficient for milk production in the net food supply, which is closely connected to efficiency in feeding and milk production.

This might be caused by the input of maize and grass silage, enabling a high energetic supply, and, on the other hand, shows a negligible fraction of heP (Wilkinson 2011; Ertl et al. 2015).

### **Soil carbon sequestration**

Soil carbon sequestration is the process of removing  $\text{CO}_2$ -equivalents from the atmosphere and temporarily accumulating them in the soil. Enhancing these processes or reducing actions leading to the release of the deposited C (such as tillage) is a major strategy in GHG mitigation in agriculture. In dairy production, grassland-based livestock systems have the potential to partly offset the climate impact of cattle farming. In fact, Janssens et al. (2005) found a carbon fixing potential of approximately 1 ton of  $\text{CO}_2$  per hectare and year. In our study, when the carbon sequestration of permanent alpine grassland areas was considered according to the methodology suggested by (Petersen et al. 2013), the sequestration had a reducing effect of 4.92 and 6.21% for the CON and ORG system, respectively, on total  $\text{CO}_2$  emissions (Table 6), which is in line with the study conducted by O'Brien et al. (2014). They found no or negligible effects of grassland C sequestration for two confinement dairy systems, with a low percentage of roughage in the diet, while the Irish grassland-based system showed a reduction of 9%. In contrast to this, Salvador et al. (2017) found significantly higher sequestration contribution to total  $\text{CO}_2$  emissions, with approximately 30%, if no allocation was performed. A higher fraction of C sequestered might be explained for the lower stocking-rate-group, but not for the high stocking-rate-group, with stocking rates higher compared to our and several previous studies (O'Brien et al. 2014; Sabia et al. 2024). In our study, the CON farms, on average, owned a higher percentage of permanent grassland due to the large alpine pasture areas. However, the C sequestration was lower in relation to the ORG group. This might be explained by the lower vegetational turnover and the lower annual forage yields (Peratoner et al. 2010), as well as manure inputs in such meadows, leading to a lower carbon turnover, and thus reduced C sequestration potential (Petersen et al. 2013; Batalla et al. 2015; Goglio et al. 2015). However, this approach does not consider the possible carbon saturation within the soil since several models predict that the soil's carbon stock can increase without limitation (Jones and Donnelly, 2004; Six et al., 2002). This assumption is crucial in understanding the long-term potential of grasslands to act as carbon sinks. However, it is important to consider that some studies

propose the possibility of a limitation to the amount of carbon that can be stored in pasture soils due to saturation (Goglio et al. 2015). For example, pastures may eventually reach a threshold where the soil's capacity to store additional carbon becomes limited, either due to the saturation of soil organic matter or through changes in environmental conditions such as temperature or moisture. This phenomenon, referred to as "carbon saturation," suggests that after a certain point, additional carbon inputs may no longer result in proportional increases in soil carbon storage. This limitation is a critical consideration when evaluating the long-term effectiveness of carbon sequestration strategies in pastures. While some studies, like that of Batalla et al. (2015), assume a consistent sequestration rate over a century, other researchers argue that a saturation point might be reached, after which the rate of sequestration could slow down or stabilise. Therefore, while the estimation of carbon sequestration is an essential part of environmental impact assessments, the possibility of carbon saturation in pastures should be considered to provide a more accurate representation of their long-term role in mitigating climate change. Communal alpine pasture areas, which are conventionally used by a higher number of farms for grazing during the summer months, were, however, used by only 7 farms from the CON group, while 12 out of the 15 ORG farms indicated that they use such pastures. These areas were not included in the calculations; otherwise, C sequestration might have been even higher for the ORG group. As O'Brien et al. (2014) O'Brien et al. (2014) found, extensive systems with a high percentage of grassland showed more favourable carbon footprint values, if grassland C sequestration was included. This shows that a high proportion of permanent grassland, and alpine pasture areas in particular, due to being high in area, might have a high climate mitigation potential.

## Conclusion

To provide a comprehensive assessment of the environmental performance of the two mountain dairy production systems examined, this study extended beyond conventional LCA by incorporating analyses of net food provision efficiency and carbon sequestration potential. The findings indicate that organically managed mountain dairy farms exert a lower overall environmental impact. However, they were less efficient in supplying human-edible protein, primarily due to suboptimal feeding strategies and lower milk yields. Carbon sequestration demonstrated a moderate potential in grasslands under both production systems, suggesting a partial mitigation

of GHG emissions through soil carbon storage. Nevertheless, the high variability observed among the organic farms in terms of farm size, management intensity, and feeding practices limited the ability to draw definitive conclusions and clear distinctions between the systems. This variability largely stemmed from challenges in recruiting farms that met all study criteria while being willing to participate. Despite these limitations, the study captures the diversity of mountain dairy farms utilising the same cattle breed and highlights variations in management approaches, environmental impacts, food supply efficiency, and carbon sequestration capacity. Ultimately, efforts to improve the environmental sustainability of mountain dairy systems should adopt a multidimensional perspective. Beyond GHG emissions, it is essential to consider the systems' capacity to convert non-edible biomass into food, their relatively low local environmental footprint, their role in preserving grassland ecosystems and cultural landscapes, and the wider ecosystem services they provide. Further investigations are necessary to gain a deeper understanding of the specific role and potential contributions of organic livestock farming in the context of Alpine agricultural systems.

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## Discloser statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Bulleled highlights

- No significant difference for GWP<sub>100</sub> was observed between investigated dairy systems
- Conventional dairy farms showed a higher land use efficiency than organic ones
- Conventional dairy farms were more efficient in providing human edible protein
- Carbon sequestration of permanent grassland did not differ between farming systems

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## Data availability statement

The data that support the findings of this study are available on request from the corresponding author, [TZ]. The data are not publicly available due to the privacy of research participants.

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## Appendix

**Table A1.** Emission factors and equations used for the estimation of environmental emissions of each pollutant in the three systems (sabia et al. 2018).

Environmental pollutant	Origin	Equations	Emission Factor	Reference
kg CH <sub>4</sub>	Enteric	$CH_4 = \text{kg DMI herd}^{-1} * 18.45$ $(\text{Gross Energy MJ kg}^{-1} \text{ DMI}) * \text{Ym}/55.65$	Ym = 4%; 6.5%	IPCC (2019) Opio et al. (2013)
	Storage and Pasture	$CH_4 = VS * B_0 * 0.67 * \text{MCF}/100 * \text{MS}$	MCF pit storage = 27 MCF pasture = 1.5 MS pit storage = 20% MS pasture = 5%	IPCC (2019)
kg N <sub>2</sub> O direct	Storage	$N_2O = \text{Nex (conf. syst.)} * \text{MS} * \text{EF} * 44/28$	0.02	Romano et al. (2023)
	Pasture	$N_2O = \text{Nex (pasture)} * \text{MS} * \text{EF} * 44/28$	0.007	IPCC (2019)
kg N <sub>2</sub> O indirect	Storage	$N_2O_{(G)} = \text{Nvolatilization} * \text{EF} * 44/28$	0.01	IPCC (2019)
	Field/Pasture	$N_2O_{(ATDN)} = [(\text{Nsn} * \text{Frac\_GasF}) +$ $((\text{Non} + \text{Nprp}) * \text{Frac\_GasM})] * \text{EF} * 44/28$ $N_2O_{(L)} = (\text{Nsn} + \text{Non} + \text{Ncr} + \text{Nsom} + \text{Nprp}) *$ $\text{Frac\_Leach} * \text{EF} * 44/28$	0.01 0.0075	IPCC (2006) IPCC (2006)
kg NH <sub>3</sub>	Storage	$\text{Nvolatilization} = \text{Nex (conf. syst.)} * \text{MS} *$ $\text{Frac\_GasMS}/100 * 17/14$	Frac_GasMS solid storage: 40	IPCC (2006)
kg CO <sub>2</sub> -eq	Diesel use	$CO_2\text{-eq.} = \text{l diesel} * \text{EF}$	3.14	Romano et al. (2023)
	Electricity use	$CO_2\text{-eq.} = \text{kWh} * \text{EF}$	0.40	Romano et al. (2023)

Ym = methane conversion factor; DMI = Dry matter intake; MCF = Methane conversion factor; MS = Manure management system usage; VS = volatile solids (3.9 kg/hd/day); B<sub>0</sub> = maximum methane producing capacity (0.1 m<sup>3</sup> CH<sub>4</sub>/kg VS); Nex = annual N excretion for livestock category; Nsn = annual amount of synthetic fertiliser N applied to soils, kg N yr<sup>-1</sup>; Non = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils kg N yr<sup>-1</sup>; Ncr = annual amount of N in crop residues including N-fixing crops, and from forage/pasture renewal, returned to soils, kg N yr<sup>-1</sup>; Nsom = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N yr<sup>-1</sup>; Nprp = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr<sup>-1</sup>, DE = Digestible Energy.

**Table A2.** Mean, median, minimum and maximum values, as well as standard deviation (SD) of milk quality data of conventionally (CON) and organically (ORG) managed farms (n = 15, respectively).

Variable	Unit	CON					ORG				
		Mean	Median	Min	Max	SD	Mean	Median	Min	Max	SD
Fat	%	4.07	3.99	2.15	6.85	0.6466	4.01	3.96	2.00	6.83	0.7167
Protein	%	3.51	3.49	2.54	5.12	0.3569	3.40	3.39	1.91	5.28	0.3740
Casein	%	2.78	2.76	0.00	4.06	0.3209	2.68	2.66	0.00	4.24	0.3531
Lactose	%	4.68	4.71	3.56	5.17	0.1830	4.60	4.62	0.98	5.32	0.2326
Urea	mg/100 ml	21.34	21.20	0.00	67.30	7.4189	21.91	21.90	0.00	56.50	8.7405
Acetone	mmol/l	-0.39	0.01	-14.7	0.9	2.4082	-0.50	0.02	-14.69	1.34	2.7310
SCC*	10 <sup>3</sup> cells/ml	133.3	67.0	3.0	991.0	172.1815	128.2	72.0	2.0	978.0	154.3967
SCS*	units	2.45	2.42	-2.06	6.31	1.7041	2.47	2.53	-2.64	6.29	1.6756
RTC*	min	20.91	20.79	7.99	38.18	3.5962	21.30	21.19	8.36	50.23	4.1536
a30*	mm	16.43	16.44	-25.65	70.90	8.2548	15.08	15.02	-51.13	82.66	8.9944
k20*	min	4.16	4.22	-3.74	10.13	1.3604	4.50	4.46	-6.41	16.85	1.6989
Unsaturated FA	g/kg	1.26	1.24	0.32	2.98	0.2303	1.27	1.26	0.33	2.56	0.2534
Monounsaturated FA	g/kg	0.88	0.85	0.25	2.54	0.2026	0.90	0.89	0.18	2.14	0.2178
Polyunsaturated FA	g/kg	0.14	0.14	0.03	0.34	0.0439	0.14	0.15	0.00	0.29	0.0484
Saturated FA	g/kg	2.43	2.39	0.84	5.45	0.4408	2.32	2.31	0.45	6.18	0.5441
Trans FA	g/100 g	1.79	1.72	0.00	6.53	0.7578	2.44	2.32	0.00	16.42	1.0899
Short chain FA	g/100 g	12.56	12.57	7.38	16.30	1.0831	12.15	12.24	7.62	16.78	1.1534
Medium chain FA	g/100 g	35.40	35.87	16.13	51.02	3.9838	34.21	34.56	15.85	68.37	5.1434
Long chain FA	g/100 g	32.10	31.42	19.15	54.73	4.5532	34.31	33.56	19.08	54.78	5.1295
C14:0	g/100 g	11.82	11.92	5.01	25.69	1.3745	11.71	11.66	6.48	25.01	1.7964
C16:0	g/100 g	27.45	27.61	14.13	49.93	2.7455	26.93	26.96	15.48	56.74	3.7326
C18:0	g/100 g	9.20	9.04	4.70	14.76	1.4239	9.55	9.46	0.00	16.86	1.4967
C18:1	g/100 g	19.37	18.99	3.78	38.37	3.1389	20.20	19.96	0.00	34.92	3.6669

\*SCC = Somatic Cell Count; SCS = Somatic Cell Score; RTC = Rennet Coagulation Time; a30 = coagulation rate; k20 = curd firmness of 20 mm; FA = Fatty Acid.