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Effect of Feed Concentrate Intake on the Environmental Impact of Dairy Cows in an Alpine Mountain Region Including Soil Carbon Sequestration and Effect on Biodiversity

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Abstract: Several studies on the environmental impacts of livestock enterprises are based on the application of life cycle assessments (LCA). In Alpine regions, soil carbon sequestration can play an important role in reducing environmental impacts. However, there is no official methodology to calculate this possible reduction. Biodiversity plays an important role in the Alpine environment and is affected by human activities, such as cattle farming. Our aim was to estimate the carbon footprint (CF) of four different dairy production systems (different in breeds and feeding intensity) by using the LCA approach. The present study included 44 dairy Alpine farms located in the autonomous province of Bolzano in northern Italy. Half of the farms (n = 22) kept Alpine Grey and the other half (n = 22) Brown Swiss cattle. Within breeds, the farms were divided by the amount of concentrated feed per cow and day into high concentrate (HC) and low concentrate (LC). This resulted in 11 Alpine Grey low concentrate (AGLC) farms feeding an average amount of 3.0 kg concentrated feed/cow/day and 11 Alpine Grey high concentrate (AGHC) farms with an average amount of 6.3 kg concentrated feed/cow/day. Eleven farms kept Brown Swiss cows with an average amount of 3.7 kg concentrated feed/cow/day (BSLC) and another 11 farms feeding on average 7.6 kg concentrated feed/cow/day (BSHC). CF for the four systems was estimated using the LCA approach. The functional unit was 1 kg of fat and protein corrected milk (FPCM). Furthermore, two methodologies have been applied to estimate soil carbon sequestration and effect on biodiversity. The system with the lowest environmental impact in terms of CF was BSHC (1.14 kg CO_2-eq/kg of FPCM), while the most impactful system was the AGLC group (1.55 kg CO_2-eq/kg of FPCM). Including the CF reduction due to soil carbon sequestered from grassland, it decreased differently for the two applied methods. For all four systems, the main factor for CF was enteric emission, while the main pollutant was biogenic CH_4. Conversely, AGLC had the lowest impact when the damage to biodiversity was considered (damage score = 0.41/kg of FPCM, damage to ecosystem diversity = 1.78 E-07 species*yr/kg FPCM). In comparison, BSHC had the greatest impact in terms of damage to biodiversity (damage score = 0.56/kg of FPCM, damage to ecosystem diversity = 2.49 E-07 species*yr/kg FPCM). This study indicates the importance of including soil carbon sequestration from grasslands and effects on biodiversity when calculating the environmental performance of dairy farms.

Keywords: dairy production; ecosystem biodiversity; damage score; carbon footprint; soil carbon sequestration; small-scale dairy farm

1. Introduction

With a share of about 18%, livestock farming is one of the strongest contributors to greenhouse gas emissions [1]. Methanogenesis in the rumen is an essential metabolic process to maintain steady state fermentation as this scavenges the molecular hydrogen generated during fermentation. The methane production from enteric fermentation in animal agriculture contributes around 20% of the total global methane [2]. Due to an overall increase in milk production by 30% and a global increase in the number of dairy cows by 11%, the dairy sector's greenhouse gas (GHG) emissions have increased by 18 percent between 2005 and 2015 [3]. According to the Intergovernmental Panel on Climate Change (IPCC), the main GHG emissions attributed to the agricultural sector are methane (CH_4) and nitrous oxide (N_2O). Life cycle assessment (LCA) is one of the most common approaches to estimate the environmental impact of a product for its entire life cycle. Several studies used LCA to estimate the impact of dairy cattle production [4,5], beef production [6,7], dairy buffalo farming [8–10], and dairy goat farming [11,12]. Carbon footprint (CF) is entirely referred to global warming potential (GWP) and it is commonly used to communicate the contribution of dairy production to climate change to stakeholders [13]. Dairy farming in the Italian Alps has transformed greatly in the last decades; between 1990 and 2010, farms declined by 60%, while the number of cows decreased by 29%, with a growth of the average herd size by 76% [14–16]. Many of these farms have abandoned traditional Alpine pasture practices by increasing the amount of concentrated feed purchased off-farm. In the Alpine region of the autonomous province of Bolzano, the indigenous breeds Alpine Grey and Brown Swiss are commonly used. Both abandonment of traditional farms or their transformation into intensive enterprises leads to a loss of open areas and forest re-growth [17], a damage of biodiversity [18–20], and a rural area undergoing radical socio-economic changes [21–23]. Only a few studies took soil carbon sequestration from grassland into account [24–26]. These grasslands may act as a carbon sink, with soil carbon sequestration of about 1 t CO_2 ha^{-1} $year^{-1}$ having been described [27]. However, there is currently no distinct approach to which methodology should be used to determine soil carbon in livestock farming systems. Another important point to consider for a proper assessment of the environmental impact generated by livestock production systems is the effect on biodiversity [28]. The damage score approach is based on the use of the characteristic factors for ecosystem damage of different land uses and agricultural practices [29]. The ReCiPe endpoint methodology is a life cycle impact assessment developed by [30] that provides harmonized characterization factors at midpoint and endpoint levels. At the endpoint level, 17 endpoint impact classes are identified and then pooled to 3 endpoint damage categories labelled as 'human health' damage, 'ecosystems', and 'resources' [30,31]. This method has been used only in a few studies on dairy farms [32–34], and it has never been used for small-scale Alpine farms. In the present study, both of the mentioned methodologies were applied to assess the effect of small-scale dairy farms on biodiversity in an Alpine environment. The aim of the present study was to investigate the effect of the used breed and the amount of concentrated feed on the carbon footprint, with and without soil carbon sequestration, and the effect on biodiversity.

2. Materials and Methods

2.1. Experimental Design and Data Collection

The present study involved 44 dairy Alpine farms located in the autonomous province of Bolzano in northern Italy. Farms were conducted from October 2017 until September 2018. Half of the farms (n = 22) kept Alpine Grey and the other half (n = 22) Brown Swiss cattle. Within breeds, the farms were divided by the amount of concentrated feed per cow and day into high concentrate (HC) and low concentrate (LC). This resulted in 11 Alpine Grey low concentrate (AGLC) farms, feeding an average amount of 3.0 kg concentrated feed/cow/day and 11 Alpine Grey high concentrate (AGHC) farms with an average amount of 6.3 kg concentrated feed/cow/day. Eleven farms kept Brown Swiss cows with an average amount of 3.7 kg concentrated feed/cow/day (BSLC) and another 11 farms feeding on average 7.6 kg concentrated feed/cow/day (BSHC). All farms were run as family businesses.

The average herd size was 12 lactating cows/farm and farms were located on average at an altitude of 1000 meters above sea level. Primary data were obtained directly from the farmers by providing a questionnaire. Table 1 shows the main characteristics of the farm groups. Using commercial software [35], the amounts of raw materials, as shown in Table 2, contained in the concentrated feed used by the farms were estimated. Based on the labeling of the individual concentrated feed and their basic analytical composition (e.g., crude protein, crude fiber) and energy composition, the percentage of raw material contained in the concentrated feed was estimated with an error of approximately ± 10%. Crop yield was estimated by using the production crop database 2017 from Italy [36]. Table 2 shows in detail the main ingredients and their chemical composition in the concentrated feeds used on the farms.

Table 1. Main characteristics of the dairy farms located in the South Tyrolean Alpine region.

	AGLC (n 11)	**AGHC (n 11)**	**BSLC (n 11)**	**BSHC (n 11)**	**S.E.M.**
Lactating cows, n°	12.3	12.8	11.5	11.9	1.2
Cattle, n°	5.5	4.2	5.6	4.5	1.1
Calves, n°	5.2 ^{a}	4.5 ^{a}	2.6 ^{b}	2.0 ^{b}	0.9
Milk yield, kg FPCM/cow/y	4206 ^{Aa}	6031 ^{Bc}	5029 ^{b}	7356 ^{Bd}	231
Concentrate, kg/cow/day	3.0 ^{A}	6.3 ^{B}	3.7 ^{A}	7.6 ^{a}	0.3
Meadow hay, ha	8.9	8.5	9.5	7.4	1.0
Permanent pasture, ha	3.4 ^{a}	2.5	2.2	0.7 ^{b}	0.8
Pasture duration, day/y	93 ^{a}	51	77	34 ^{b}	16
Altitude of farms, m.s.l.	1147	1286	1262	1206	88
Electricity, kWh/y	8260	7272	5622	8317	1873
Fuel, liter/y	977	948	1138	1335	224

AGLC: Alpine Grey low concentrate; AGHC: Alpine Grey height concentrate; BSLC: Brown Swiss low concentrate; BSHC: Brown Swiss height concentrate; FPCM: fat and protein corrected milk; S.E.M.: standard error of mean. AB $P \leq 0.001$; ab $P \leq 0.01$; Ab $P \leq 0.001$; cd $P \leq 0.001$.

Table 2. Main ingredient and chemical composition (mean ± S.D.) of feed concentrates used in dairy farms in the South Tyrolean Alpine region.

Ingredient (% of DM)	**AGLC (n = 11)**	**AGHC (n = 11)**	**BSLC (n = 11)**	**BSHC (n = 11)**
Maize flour	29 ± 3	29 ± 3	28 ± 1	29 ± 3
Wheat bran	23 ± 9	26 ± 13	20 ± 11	26 ± 11
Soy bean meal	8 ± 3	11 ± 4	11 ± 5	13 ± 4
Rapeseed meal	9 ± 4	8 ± 4	8 ± 5	8 ± 5
Alfalfa, artificially dried	7 ± 15	7 ± 15	5 ± 9	2 ± 6
Sugar beet pulp	7 ± 6	4 ± 7	7 ± 6	2 ± 6
Sunflower meal	7 ± 3	3 ± 4	5 ± 4	3 ± 4
By-products of distillation	7 ± 3	3 ± 4	5 ± 4	3 ± 4
Sugar cane	2 ± 1	2 ± 1	2 ± 1	2 ± 1
Barley flour	1 ± 2	4 ± 7	1 ± 5	5 ± 8
Chemical composition (% of DM)				
Crude protein	16.8 ± 1.9	16.5 ± 2.1	18.0 ± 1.2	17.9 ± 1.9
Crude fiber	8.2 ± 3.7	9.1 ± 3.5	7.6 ± 2.8	7.0 ± 1.8
Ether extract	3.4 ± 0.4	3.4 ± 0.6	3.4 ± 0.3	3.8 ± 0.5
Crude ash	5.8 ± 0.5	5.8 ± 0.5	6.0 ± 0.4	6.2 ± 0.6
Net Energy Lactation (MJ)	7.0 ± 0.4	7.1 ± 0.4	7.0 ± 0.3	7.1 ± 0.2

AGLC: Alpine Grey low concentrate; AGHC: Alpine Grey high concentrate; BSLC: Brown Swiss low concentrate; BSHC: Brown Swiss high concentrate; DM: dry matter.

2.2. *Method for Carbon Footprint Calculation*

By using the LCA approach, CF values were calculated. The CF was assessed using the software package SimaPro 8.01 PhD. In particular, the ReCiPe method midpoint/endpoint (H) V1.10/Europe Recipe H/A module of this package was used. CF is the net GWP emission per production unit and needed to express the functional units (FU). To calculate the GWP, the LCA approach suggested by [37] was used, and in addition the indications from [1].

2.2.1. Functional Unit and System Boundaries

Following the indications given by the Food and Agriculture Organization and the International Dairy Federation [38] for the evaluation of the CF of dairy production, 1 kg of fat and protein corrected milk (FPCM) was used as the FU:

$$1 \text{ kg FPCM} = \text{raw milk (kg)} * (0.337 + 0.116 * \text{fat content (\%)} + 0.06 * \text{protein content (\%)}).$$

System boundaries from "cradle to farm-gate" included all farm activities (on-farm and off-farm), except machinery construction, building construction, and medicines.

2.2.2. Emission Calculations for Carbon Footprint Assessment

The total emissions were estimated for each farm system including enteric fermentation, manure management, fuel and electric consumption, permanent pasture management, meadow hay production, and also the off-farm production of concentrated feed. For estimations of CH_4 enteric fermentation and manure emission and management, we applied the equation (10.21) Tier 2 method suggested by [1]:

$$EF = [GE * (Y_m/100) * 365 / 55.65];$$

where:

EF = emission factor, kg CH_4 head^{-1} y^{-1};
GE = gross energy intake, MJ head^{-1} day^{-1};
Y_m = methane conversion factor, % of gross energy in feed converted to methane (4% for young cattle and 6% for lactating cows, [39]).

For estimation of GE, the equation (10.16) suggested by [1] was used.

For estimations of the dry matter intake (DMI) for mature dairy cows, the equation (10.18b) suggested by [1] and [40] was used:

$$DMI = [((5.4 * BW)/500)/((100\text{-}DE\%)100))];$$

where:

BW = live body weight, kg (Alpine Grey was 550 kg; Brows Swiss was 650 kg);
DE% = digestible energy expressed as a percentage of gross energy was 60%.

According to the method suggested by [41] for the estimation of CH_4 emission from manure management, we used the equation (10.22). For calculation of direct N_2O (kg y^{-1}) emission from manure management, we used the equation (10.25) suggested by [41]. For this equation, the emission factor was 0.005 for solid storage and 0.01 for pasture kg N_2O-N/kg N N_2O. Indirect emissions of N_2O were estimated according to the method suggested by [41], as shown in equation (10.27), based on NO_3 leaching-runoff and the emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3-N + NO_x-N volatilized) $^{-1}$ default value was 0.01 kg N_2O-N (kg NH_3-N + NO_x-N volatilized) $^{-1}$. The emission generated from diesel and electric consumption for agricultural practice were estimated from farmers' information, as shown in Table 1. In particular, we used 0.85 kg per liter as a standard value for diesel density. The emission factor for Italy was 3.13 kg CO_2-eq for burning 1 kg of diesel [9,25]. Regarding electricity, the emission factor was set at 0.47 kg CO_2-eq per kWh using national emission factors [42]. The database from [43] was used to estimate the impact of concentrate production off-farm. The fuel consumption for the delivery of the concentrated feed to the farms was also considered.

2.3. Soil Carbon Sequestration

Soils are the largest carbon reservoir of the terrestrial carbon cycle. However, there is no official method to estimate soil carbon for livestock farms and only a few studies have investigated this factor [24,25]. Different agricultural practices and land use can have significant effects on carbon stored in the soil. In the present study, two different methodologies were used to estimate the reduction of carbon footprint by taking carbon sequestration into account.

2.3.1. Soil Carbon Sequestration

Soussana et al. [44] approached this method based on the net carbon fluxes. These authors studied the role played by the soil and pasture in sequestrating carbon as a sink and mitigating its effects. However, the emissions of CH_4 and N_20 should be reduced while preserving soil carbon storage. In particular, agricultural practices that prevent carbon sinks should be avoided. Grassland management implies a high level of uncertainty. In our study, we used the mean value reported by [44], corresponding to 22 g C/m^2 for our estimates.

2.3.2. Soil Carbon Sequestration

The methodology suggested by [45] is based on a 100-year perspective and is when 10% of the total carbon added to the soil will be sequestered. These authors also give relevance to the potential played by soils for carbon sequestration as a suitable strategy to reduce GHG emissions. As suggested by [44,45], carbon change estimates are based on net carbon fluxes. Herbage residues and manure were included in the computation of the annual inputs of carbon into grassland. The former was calculated according to [24]. These authors considered above- and below-ground residues at 40% and 16% of total yield, respectively, and assumed a 45% content of C on a dry matter basis.

2.4. Damage on Biodiversity

Biodiversity can be defined as the genetic variability among any organisms living in the marine environment, in other aquatic systems, on land, or in the ground. Biodiversity, therefore, concerns the diversity in terms of ecosystems, between species and within species. Agricultural practices and the consequent land use may markedly damage biodiversity. In this study, we used two different methodological approaches to evaluate biodiversity damage.

2.4.1. Biodiversity Damage Score

The loss of biodiversity was estimated as suggested by [29,46]. This method is based on the use of characterization factors (CFs). The damage score (DS) was used to express the impact on biodiversity. This score measures the relative change in the number of species detected in the occupied area as compared with the baseline. Table 3 shows the CFs used to evaluate biodiversity damage in this study. The local DS was estimated for 1 m^2 of farmland and then related to 1 kg of FPCM.

$$DS = CFs * A * t$$

where:

DS = damage score;
CFs = characterization factors, as shown in Table 3;
A = area occupied (m^2);
t = time (years).

Table 3. Characterization factors of land use type [29].

Land Use Type	Median	95% Confidence Level
Organic fertile grassland	−0.01	−0.18–0.15
Organic tall grassland	0.04	−0.12–0.18
Less intensive arable land	0.44	0.31–0.54
Intensive arable land	0.79	0.73–0.83
Baseline: semi-natural woodland	0.00	n.a.

2.4.2. Damage to Ecosystem Diversity

The damage to ecosystem diversity is expressed in number of species per year and represents the loss of species over a specified period of time and in a given geographical local area. Carried out on commercial software SimaPro 8.01 PhD, the ReCiPe endpoint method approached the damage on ecosystems and biodiversity per 1 kg FPCM. This is a life cycle impact assessment developed by [30] that provides harmonized characterization factors at midpoint and endpoint levels. At endpoint level, 17 endpoint impact classes were identified, and damage categories labelled as 'ecosystems' were studied.

2.5. Statistical Analysis

The data at farm level, carbon footprint, main processes, main pollutants, and indicator of damage to biodiversity were analyzed by using one-way (general linear model procedure) ANOVA, using the farming systems as a factor. A correlation analysis was used to examine the relationship between the two methods of damage score estimation. The farm was used as an experimental unit. Therefore, the correlation coefficients were calculated using either Pearson tests according to the data distribution of the variables. Data were analyzed using SAS software (SAS Institute Inc., Cary, NC). Significance was accepted at $P < 0.05$.

3. Results and Discussion

3.1. Farm Levels

Table 1 shows the main characteristics of the four farming systems. The number of lactating cows averaged 12 without a significant difference between the four systems. It could be observed that small scale dairy farms in the Alpine area were mainly family businesses. Salvador et al. [25] observed an average number of lactating cows between 8.7 and 40.6 in the Alpine systems, whereas [47] found an average of 14.0 lactating dairy cows per farm, and [15] observed on average 12.8 dairy cows per dairy farm in the Italian Alps. In terms of milk production, a significant difference was found between the systems, as shown in Table 2. The AGLC system shows significantly lower kg of FPCM per cow per year compared to all other three systems (4206 ± 231 kg of FPCM/cow/year), whereas the BSHC system shows higher milk production of FPCM than any other system (7356 ± 231 kg of FPCM/cow/year). The differences observed were most probably due to a breed effect (Alpine Grey vs. Brown Swiss). Furthermore, several studies observed an increase in milk production due to an increased amount of concentrated feed [48–50]. For both breeds considered in this study, an average increase of about 50% in the quantity of concentrated feed was accompanied by an increase of on average 30% in the milk quantity, as shown in Table 2. In terms of land use for hay production, no significant difference was found between the groups, while in the AGLC system there was a significantly larger use of permanent pasture grazing resources compared to the BSHC system, and also the average number of days on pasture was higher ($P < 0.01$). The breeding of the Alpine Grey dairy cow was at one of the oldest and most traditional farms in the province of Bolzano, and most probably the change to other breeds of dairy cows and the increased use of commercial feed have led to a gradual reduction of use of the pasture resource. No significant difference was found for the general consumption of electricity and diesel.

3.2. Carbon Footprint Without Soil Carbon Sequestration

The carbon footprint generated from the four different systems per kg of FPCM is shown in Table 4. The system AGLC has the highest CF, differing significantly from all other systems. The AGLC system had an impact of about 26% greater than the BSHC system ($P < 0.001$), and about 21% greater than the AGHC system ($P < 0.01$), while no significant difference was found compared to the BSLC system. The AGHC system showed significantly less impact than the BSLC system (1.22 vs. 1.43 kg CO_2-eq per kg FPCM respectively, $P < 0.01$), whereas no significant difference was observed between the AGHC and the BSHC system. In terms of the global warming potential, recent studies conducted in the Alpine region showed an environmental impact between 1.94 and 1.59 kg CO_2-eq per kg FPCM [25], while [32] observed 1.60 kg CO_2-eq per kg FPCM. Similar results were observed by [51] in southern Germany (1.53 kg CO_2-eq/kg FPCM). Other authors showed lower values in the Alpine area similar to ours. Penati et al. (2013) [52] observed values of 1.14 kg CO_2-eq per kg FPCM, whereas [53] in Switzerland observed results of 1.08 kg CO_2-eq per kg FPCM. The results obtained from several studies were all dependent on the production of milk. From an environmental point of view, a system that produces more milk is more efficient. The BSHC system showed an average milk production of 7300 kg FPCM per cow, while the least productive system (AGLC) achieves an average milk yield of 4200 kg FPCM per cow and lactation. Most probably, the differences observed compared to other studies conducted in the same geographical area were due to the different milk production levels from different breeds studied and differences in management practices. Nevertheless, our results are in the ranges indicated by [3]. The main processes contributing to CF are shown in Table 5. The enteric emission from different systems was the process with the highest impact, followed by the production of concentrated feed and meadow hay. The two systems with lower amounts of concentrated feed (AGLC and BSLC), showed a greater impact generated from enteric emissions than the two systems with a high use of concentrated feed. This is most probably due to the use of cows fed with a greater amount of raw fiber, which can generate a greater impact due to the process from enteric fermentation. In a recent report by [2], enteric fermentations were responsible for about 58.5% of total emissions, while [32] observed a range between 44.1% and 65.9%, and [54] observed a value of 48.4% in organic dairy cow farms. In cows, as in other ruminants, CH_4 is emitted as a direct result of fiber hydrolysis. In particular, in the rumen a number of fermentative processes occur, resulting in the production of important nutrients, such as volatile fatty acids and proteins of bacterial origin deriving from the fermentation of vegetal fibers. Table 6 shows the main pollutants in the different systems. The AGLC system shows a high emission of CH_4 biogenic compared to other systems. Several studies tried to understand how to reduce the impact generated by enteric fermentations from ruminants; [55] showed that concentrate supplementation on great quality pasture-only diets have the possibility to decrease CH_4 emissions. Jiao et al. (2014) [48] observed a reduction in CH_4 enteric emissions in dairy cows fed with an increased amount of concentrate feed in the diet, whereas [56] suggested several feeding strategies to minimize the emissions of enteric methane, such as an increase of the voluntary feed intake on permanent pasture. As reported by [57], estimation of in vitro methane production in buffalo and dairy cow feedstuffs are characterized by high structural glucides of low quality. They consequently result in a high CH_4 production in both species. Studies indicate that the use of saponins in ruminant feed rations may reduce the production of biogenic methane [58–60], while [61–63] indicate that the inclusion of more digestible forages in ruminant diets may reduce emissions from the ruminant's fermentation. This is in line with the equation (10.18b) suggested by [1]; the digestibility of feed ingested by ruminants plays a key role in the emission factor. The second main process responsible for CF was the off-farm production for concentrated feed, as shown in Table 5. This process was significantly higher in the BSHC system than in other systems; conversely, the AGLC and BSLC systems showed a lower amount of CF in this process (12.2% and 11.9%, respectively). This corresponds to the larger and lower use of purchased feed in systems. The two main pollutant compounds present for this process were CO_2 and N_2O, as shown in Table 6. Salvador et al. (2016) [64] observed that 14.4% of total CF was due to purchased feed in organic dairy cow rearing systems in the Alpine, while [65] in buffalo farms observed a proportion of 30%. Table 5 shows that AGLC systems produce more hay than the two systems with higher amounts of concentrates; this is most probably due to more permanent grassland present in the AGLC system, as shown in Table 1. No significant differences were observed in terms of general consumption between the different systems.

Table 4. Carbon footprint (kg CO_2-eq) per 1 kg of FPCM generated by different concentrated feed systems before and after including methods of carbon soil sequestration.

	AGLC (n = 11)	AGHC (n = 11)	BSLC (n = 11)	BSHC (n = 11)	S.E.M.
CF (kg CO_2-eq/kg FPCM), without soil carbon sequestration	1.55^{Aa}	1.22^{b}	1.43^{a}	1.14^{Bb}	0.06
CF (kg CO_2-eq/kg FPCM), including soil carbon sequestration [44]	1.33^{Aa}	1.06^{b}	1.23^{a}	1.00^{Bb}	0.06
Reduction of environmental impact (kg CO_2-eq/kg FPCM) [44]	0.23^{Aa}	0.16^{b}	0.21^{a}	0.13^{Bb}	0.01
% ON-Farms [44]	79.7	69.3	81.7	57.6	9.1
CF (kg CO_2-eq/kg FPCM), including soil carbon sequestration [45]	1.22^{Aa}	1.00^{b}	1.17^{a}	0.98^{Bb}	0.05
Reduction of environmental impact (kg CO_2-eq/kg FPCM) [45]	0.34^{Aa}	0.23^{b}	0.26^{a}	0.17^{Bb}	0.02
% ON-Farms [45]	84.0	86.1	83.9	60.9	8.2

AGLC: Alpine Grey low concentrate; AGHC: Alpine Grey high concentrate; BSLC: Brown Swiss low concentrate; BSHC: Brown Swiss high concentrate; FPCM: fat and protein corrected milk; S.E.M.: standard error of mean; CF: carbon footprint. AB $P \leq 0.001$; ab $P \leq 0.01$.

Table 5. Main processes responsible for the carbon footprint generated in the different farms (% on total greenhouse gas emissions).

Process	AGLC (n = 11)	AGHC (n = 11)	BSLC (n = 11)	BSHC (n = 11)	S.E.M.
Enteric fermentation	65.2^{a}	56.6^{b}	68.2^{a}	56.2^{b}	1.8
Concentrated feed	12.2^{A}	22.1^{Ba}	11.9^{A}	27.5^{Bb}	1.8
Meadow hay	8.8^{Aa}	6.2^{b}	8.0	4.9^{B}	1.0
General consumptions	8.0	10.0	8.1	8.0	1.8

AGLC: Alpine Grey low concentrate; AGHC: Alpine Grey high concentrate; BSLC: Brown Swiss low concentrate; BSHC: Brown Swiss high concentrate; S.E.M.: standard error of mean. AB: $P \leq 0.001$; ab: $P \leq 0.01$.

Table 6. Main pollutants responsible for the carbon footprint generated in the different farms (% on total greenhouse gas emissions).

Pollutant	AGLC (n = 11)	AGHC (n = 11)	BSLC (n = 11)	BSHC (n = 11)	S.E.M.
CH_4 biogenic	75.0^{Aa}	65.9^{b}	70.2^{ab}	57.8^{B}	1.8
CO_2 fossil	11.5^{a}	14.3^{a}	17.2^{b}	19.9^{b}	1.8
N_2O	11.6^{Aa}	14.7^{b}	10.5^{Aa}	16.8^{B}	1.0

AGLC: Alpine Grey low concentrate; AGHC: Alpine Grey high concentrate; BSLC: Brown Swiss low concentrate; BSHC: Brown Swiss high concentrate; S.E.M.: standard error of mean. AB: $P \leq 0.001$; ab: $P \leq 0.01$.

3.3. Carbon Footprint Including Soil Carbon Sequestration

Table 4 shows the results of the CF including the reduction due to carbon sequestered from the soil following the methodologies by [44,45]. The amount of CO_2-eq reduction depends on the method used. The reduction observed varies from 12.2% to 14.2% with the methodology suggested by [44] and between 14.0% and 21.2% using the method suggested by [45]. In a study on dairy sheep farming, [24] observed a reduction between 2% and 43% when using the Soussana et al. [44] model and a reduction of 3% to 41% when using the Petersen et al. [45] model. On dairy farms, [25] observed an average reduction by 29.7%, while [33] stated that the reduction by soil carbon sequestration to be negligible. For both methodologies, the differences observed between the four systems were maintained. In particular, the two systems with the use of low concentrated feeds (AGLC and BSLC) show a greater reduction in terms of CF at the on-farm level than systems with high concentrated feed use, and this is most probably due to a greater use of local resources, such as extensive permanent pasture and meadow hay production in the region. This may indicate that the less resources used off-farm (such as concentrated feed), the greater the benefit from soil carbon sequestration. For both methodologies, BSHC was the most efficient system when it came to the reduction of CF by soil carbon sequestration. With the methodology suggested by Petersen et al. [45], the CF generated by the BSHC system was 0.98 kg CO_2-eq per kg of FPCM, while the most impactful system remains the AGLC, with 1.33 kg CO_2-eq (with the method in [44]) and 1.22 kg CO_2-eq (with the method suggested by [45]). Without these methodological differences, the results show that there is a possibility for permanent soil carbon sequestration in these systems if the same amount of C was added to the grasslands every year. This should be included in the CF methodology and it is possible to add the consequence of soil carbon sequestration in the CF [45]. Recent studies have observed that high levels of organic matter in the soil may contribute to lower GHG emission in the atmosphere and mitigate climate change [66]. This highlights the importance of including soil carbon sequestration in LCA due to the climate mitigation of Alpine grazing systems, and the probability of having a lower CF in extensive systems when soil carbon sequestration is included, as [67] pointed out in their study for dairy systems in Ireland.

3.4. Effect on Biodiversity with Two Different Methods

The results from the indicators of damage on biodiversity in different farm systems per 1 kg of FPCM are reported in Table 7. For both methods considered, the BSHC system showed a significantly higher damage to biodiversity compared to the other systems. In BSHC, the value observed was 0.52 DS per kg of FPCM, while the AGLC system showed the lowest value with 0.41 DS per kg of FPCM ($P < 0.001$). Guerci et al. [32], in a study conducted in EU farms, observed a DS between 0.25 and 1.25, with lower values observed for organic farms. Battini et al. [29] showed a DS no-allocation between 0.75 and 2.40. The AGLC system has a lower use of concentrated feed. It is well known that the production of concentrated feed needs less land but is accompanied by a greater damage to biodiversity, so that the characterization factor used for intensive arable land was 0.79, while organic fertile grassland has been used with a value equal to −0.01, as shown in Table 3. Therefore, the AGLC system goes along with greater benefits to biodiversity. Tumisto et al. [46] observed that some other types of nature reserves or natural meadows may have a greater level of biodiversity than natural forests, whereas meadows that change into other crop production are a driver of habitat loss and thus have a documented negative effect on general biodiversity [68]. A recent study conducted in the Alpine environment [20] observed that the abandonment of pastures, mountain pastures, and advancing forest reduces the biodiversity of vertebrates living in mountain streams. The results show the same trend when analyzed with the ReCiPe endpoint methodology [30]. BSHC showed a greater impact in terms of damage to biodiversity with a damage score of 2.49 E-07, higher than other systems, as shown in Table 7. Kaenchan et al. [69] claimed that land use can have negative effects on the ecosystem including humans, whereas [70] stated that the preservation of extensive agricultural systems, including species-rich meadows, is crucial for the maintenance of the biodiversity in semi-natural management conditions. Du et al. [71] observed that the production of manually harvested sugarcane generated damage to the species of 3.11 E-07, whereas the estimated damage to ecosystem diversity caused by mechanically harvested sugarcane was 2.38 E-07. In a recent study, Sabia et al. [34] observed that for 1 kg of sheep milk using the ReCiPe endpoint approach, the impacts in terms of damage on biodiversity was equal to 3.29 E-07 species*year. Steinmann et al. [72] observed that this damage can be the result of the combination of land and energy footprints. In addition, [73] observed that agronomic practices may undermine both soil and water quality while also negatively affecting the natural biodiversity through, for example, N deposition in ecosystems. In order to promote a balance between damage and restoration (i.e., compensation), the monetization of the environmental impact is necessary to combine all estimations of the ecological damage into one single value [74]. In a recent study conducted at the European level on the impact of total food consumption on biodiversity using the ReCiPe endpoint approach, Crenna et al. [75] observed that the damage produced in terms of species*year was equal to 3.34 E-05 per capita consumption. Figure 1 shows that a relative positive strong correlation was found between the two methods ($r = 0.73$, $P \leq 0.001$). The two methodologies are very similar and have different points of affinity. The methodology of DS approaches through characterization factors, while the ReCiPe endpoint method is the category 'ecosystems' expressed in number of species per year and represents the loss of species over a specified period of time and in a given geographical area. Both methodologies have a direct approach to land use, land use change, and local geographical effects. However, there is no official methodology on how to approach the damage to biodiversity generated by livestock farming systems and, in particular, by dairy cows.

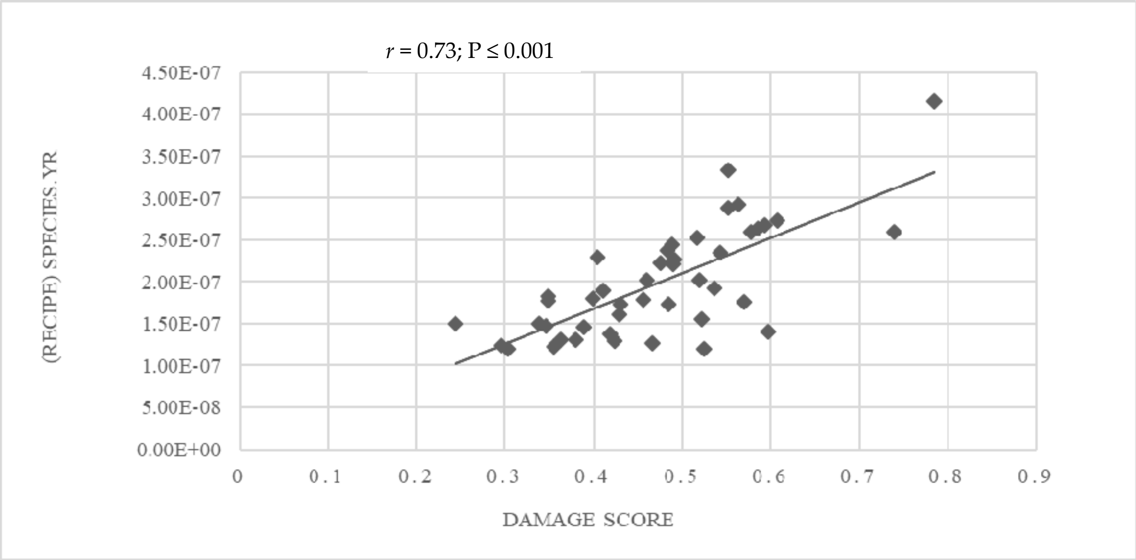

Figure 1. Pearson correlation coefficient (r) between two methods used for estimation of damage to biodiversity per kg of FPCM (FPCM: fat and protein corrected milk).

Table 7. Indicators of damage to biodiversity in different farm systems.

	AGLC (n = 11)	**AGHC (n = 11)**	**BSLC (n = 11)**	**BSHC (n = 11)**	**S.E.M.**
Biodiversity, DS/kg FPCM [30]	0.41 ^{A}	0.46 ^{A}	0.44 ^{A}	0.56 ^{B}	0.03
Damage to Ecosystem Diversity (Species*y)[1]/kg FPCM [31]	1.78 E-07 ^{a}	2.09 E-07 ^{ABab}	1.60 E-07 ^{A}	2.49 E-07 ^{Bb}	1.75 E-08

AGLC: Alpine Grey low concentrate; AGHC: Alpine Grey high concentrate; BSLC: Brown Swiss low concentrate; BSHC: Brown Swiss high concentrate; S.E.M.: standard error of mean; DS: damage score; [1] unit of species*y is the weighted damage on the basis of the total number of species on land and in water bodies [31]; AB: $P \leq 0.001$; ab; $P \leq 0.01$.

4. Conclusions

This study has taken into account small-scale Alpine dairy farms with different amounts of concentrated feed and either the breed Alpine Grey or Brown Swiss. The BSHC system was the most environmentally efficient system in terms of carbon footprint per kg of FPCM. However, the two systems using the Alpine Grey breed showed satisfactory environmental performance even though the AGLC system was less efficient. For all four systems, the main factor responsible for the carbon footprint was the enteric emission. Thus far, there is no generally accepted methodology to estimate the contribution from soil carbon sequestration in LCA. We took into account the soil carbon sequestered from grassland, which reduced the carbon footprint and depended on the method used. For biodiversity damage, the least impacting system was AGLC, while the system with the highest damage score was BSHC for both applied methods. Strong positive correlations were found between the results of damage to biodiversity for the two methods. More studies are needed to define the correct approach and methodology to determine the reduction due to carbon sequestration in soils and effect on biodiversity.

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