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Research article

Carbon footprint of dairy goat production systems: A comparison of three contrasting grazing levels in the Sierra de Grazalema Natural Park (Southern Spain)

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ABSTRACT

The main objective of this study was to analyze the carbon footprint (CF) of grazing dairy goat systems in a natural park according to their grazing level. A total of 16 representative grazing goat farms in southern Spain were selected and grouped into three farming systems: low productivity grazing farms (LPG), more intensified grazing farms (MIG) and high productivity grazing farms (HPG). Their CF was analyzed, including greenhouse gas emissions and soil C sequestration according to the farms' grazing level and milk productivity, taking into account different functional units (one kilogram of fat and protein corrected milk (FPCM) and one hectare) and milk correction. Results showed that all variables differed according to the milk correction applied as the values for cow's milk correction were 41% lower than for sheep's milk correction. Total emissions and contributions of soil carbon sequestration differed according to farming system group; LPG farms had higher total emissions than MIG and HPG farms, however total carbon sequestration was lower in the MIG farms than in the LPG and HPG farms. The CF values ranged from 2.36 to 1.76 kg CO_2e kg^{-1} FPCM for sheep's milk correction and from 1.40 to 1.04 kg CO_2e kg^{-1} FPCM for cow's milk correction. No differences were found between farming system groups in either of the two cases but when calculations took hectare of land as a functional unit, the contribution of MIG farms to the CF was 85% higher than LPG and HPG farms. Therefore it is important to take into account the functional unit used to calculate the CF by analyzing this indicator in a broader context, and including carbon sequestration by grazing livestock in the calculation. In order to reduce the CF of this type of system, it is advisable to make appropriate use of the natural resources and to reach an optimum level of milk productivity, high enough for pastoral livestock farming to be viable.

1. Introduction

Most of the European Natura 2000 network is in Spain. A quarter of Spain's territory is dedicated to nature conservation with a total of 1958 protected natural areas, covering over 22 million hectares (Múgica et al., 2017). Twenty four percent of Natura 2000 surface area is used for agriculture or agroforestry (crops, steppes, agriculture mosaics, open forest, etc.), contributing directly to food and feed supply. In Spain, around 13% of the area is protected under one of several legal figures. A large part of these landscapes are grazed, particularly by cattle, sheep or goats for meat production (Bernués et al., 2017), and dairy goats in protected landscapes in the Southeast and in other areas unsuitable for agriculture in Mediterranean zones (Castel et al., 2010; Mena et al., 2017; Dubeuf et al., 2018). In these areas, small ruminant farming is often one of the few economically viable activities as not only does it fix population but it also manages landscapes and maintains ecosystems to conserve biodiversity and provide niche products for the market (Robles et al., 2009; Ruiz-Mirazo et al., 2011).

Nevertheless, the livestock sector also has an important influence on climate change, biodiversity loss and degradation of land and freshwater because of its emissions to the air, water and soil (Foley et al., 2011; Gerber et al., 2013). In fact, livestock farming is estimated to contribute to about 18% of total global greenhouse gas (GHG) emissions, considering direct and indirect land use (Hristov et al., 2013; Herrero et al., 2016). Ruminants are responsible for the largest share of enteric fermentation and manure production (Zervas and Tsiplakou,

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2012; Buratti et al., 2017), although ruminant farming systems vary depending on physical conditions such as climate, soil type, altitude and landscape, (Gibon et al., 1999; Hadjigeorgiou et al., 2005), specie (cow, goat, sheep) and production purpose (dairy or meat).

For calculating GHG emissions of agricultural products, absolute and efficiency measures have to be differentiated, as they can produce different outcomes (Rivera-Ferre et al., 2016). The use of an efficiency parameter such as *emission* per *unit of product*, can infer that a certain sector is reducing its contribution to GHG emissions, even though its absolute parameter, namely *total emissions*, increases. However, the most commonly used indicator of the contribution of a given product to GHG emissions is an efficiency parameter: the Carbon Footprint (CF), expressed in kg of CO_2e per unit of product. The last one is called "functional unit" (Sinden, 2009), the choice of which has to be carefully defined in accordance with the overall purpose of the study (de Vries et al., 2015) because conclusions could be different (Röös et al., 2013). Using only a mass-based functional unit, predominant in current life cycle assessment practice, does not provide a balanced view of the impacts of intensification. The use of an area-based functional unit, in addition to a mass-based one, can provide more information about the environmental consequences of agricultural system intensification (Salou et al., 2017). Area-based or mass-based functional units are normally used as functional units in the CF for plant products. Nevertheless, for livestock products, given the existence of indoor animal production systems (e.g. poultry farms), the CF is mostly expressed by kg of product.

Another key aspect in grazing farming systems' contribution to climate change is not only to calculate GHGs but also to consider soil carbon (C) sequestration from soil C inputs from crop residues or manure, for example (Batalla et al., 2015). In this sense, there has been more discussion about the need to assess the ecosystem services offered by forage-based livestock systems in disadvantaged areas, paying particular attention to GHG emissions and their mitigation by C sequestration (Battaglini et al., 2014). Nevertheless as C sequestration is difficult to estimate, most researchers only consider emissions and C sequestration is not generally taken into account for calculating CF (Booker et al., 2013; McDermot and Elavarthi, 2014; Rivera-Ferre et al., 2016; Buratti et al., 2017).

The main objective of this study is to analyze the C footprint (including GHG emissions and soil C sequestration) of grazing dairy goat systems in a natural park according to their grazing level and milk productivity, taking into account different functional units. Particular attention is paid in this study to providing comprehensive information on the role of grassland and shrubland on GHG balance since the hypothesis in this study assumes that the systems based on natural pasture instead of feed and concentrates may have a smaller CF.

2. Material and methods

2.1. Experimental farms and data collection

The study was carried out in the Sierra de Grazalema Natural Park (36° 35′N, 5° 26′W, southern Spain), one of Spain's most ecologically outstanding areas (Biosphere Reserve, UNESCO). Altitudes range between 650 and 1200 m and the geological substratum is dominated by dolomite, limestone and loam, with basic soils (Gallego Fernández and García Novo, 2002). The study area has a Mediterranean climate, with cool, wet winters (mean 8 °C) and warm, dry summers (mean 25 °C). The mean annual precipitation (960–2220 mm) is the most determinant climatic variable associated with plant growth and community distribution. The study area is characterized by the coexistence of a mosaic of dehesa (open forest), dense *Quercus ilex*, *Q. suber* and *Q. faginea* forest. Plant communities are generally dominated by sclerophyllous woody plants with a herbaceous or shrubby understory (Costa et al., 2006).

Based on the researchers' previous experience (Gutierrez-Peña et al., 2016; Mena et al., 2017), sixteen commercial farms were selected to be representative of the diversity of the grazing goat farm systems in the area. According to Gutierrez-Peña et al. (2016), feeding management is based on the grazing of natural grasslands, namely pastures, shrubs and trees. Goats receive supplementary feed indoors, mostly during the milking period. They kid once a year, with an average milking period of between six and eight months and are milked once or twice a day, according to their productive level. Kids are reared naturally for approximately one month and then sent to slaughter.

According to Mena et al. (2017), these sixteen grazing goat farms were classified into three types: low productivity grazing farms (LPG) with small herds and low productivity farms with little dependence on external inputs for animal feeding; more intensified grazing farms (MIG) with medium herd sizes and high-medium productivity farms that depend mostly on external inputs for animal feeding; and high productivity grazing farms (MPG) with large herds and high-medium productivity farms with little dependence on external inputs. Number of goats per farm were 174, 251 and 572, respectively; Natural pasture area (ha) was 67, 42 and 255, respectively; Crop pasture area (ha) was 6, 8 and 30, respectively; and Net energy obtained from grazing (%) was 47, 19 and 47, respectively.

The farmers were visited monthly throughout 2011 to gather all the necessary information about inputs and outputs and animal management practices to calculate the CF. The agricultural cooperative association, food suppliers and cheese industries that bought the milk also provided information.

2.2. Calculation of the CF of goat's milk

2.2.1. Boundary of the system for GHG emissions

The boundary chosen for the goat milk production system was "from cradle to farm gate" and included all the on-farm and off-farm emissions. Machinery, buildings, medicines and other minor stable supplies were excluded from the assessment.

"On farm emissions" refer to all emissions from livestock (enteric fermentation) and soil management (mainly N_2O emissions). The IPCC (2007) guidelines have been followed, using the Tier 2 approach taking national and local values for the farms studied (MAGRAMA, 2012). The emissions are expressed in CO_2 equivalents in a 100 year global warming potential (GWP) of CH_4 and N_2O of 25 and 298, respectively, following IPCC guidelines (IPCC, 2007). "Off farm emissions" correspond mainly to the processing and transport of all the inputs used on the farms. A combination of emissions factors and data from literature has been used, mainly using Dia'terre® (Ademe, 2011) and Gac et al. (2010).

For C sequestration, the authors followed the methodology of Petersen et al. (2013), which takes into account a 100 year perspective to allocate soil C changes, as well as the GWP of livestock emissions. In goat systems, soil C changes are affected mainly by annual C inputs in soils, which in this study are directly related to C from crop residues (above and below-ground) on the farms and C inputs from manure (spread by the farmers directly on the pastures).

2.2.2. Functional units

Emissions are expressed in two functional units to ensure that the results reported are consistent and functional. The first functional unit is one kg of fat and protein corrected milk (FPCM) as recommended by the most common life cycle analysis guidelines for the dairy sector (IDF, 2010). As goat's milk does not have a specific reference, ewe's milk and cow's milk have been used for the standardization:

- 1 kg of fat and protein corrected milk (FPCM), as Pulina et al. (2005) proposed for dairy ewe's milk (milk correction 1). The final equation for calculating goat FPCM is:

FPCM (kg) = raw milk (kg) x [0.25 + 0.085 $\times$ fat content (%) + 0.035 $\times$ protein content (%)]

- 1 kg of fat and protein corrected milk (FPCM), as Robertson et al. (2015) proposed for dairy cow's milk (milk correction 2). The final equation for calculating goat FPCM is:

FPCM (kg) = raw milk (kg) x [0.145 $\times$ fat content (%) + 0.092 $\times$ protein content (%) + 0.3].

The second functional unit used is 1 ha of utilizable agricultural land (UAL) on the goat farm.

2.2.3. *Allocation*

Although milk is the main product obtained from a dairy goat farm, total emissions must be allocated because meat is a co-product with a market value. In this study the economic allocation principles were based on kids being sold at 1 month of age, with a live weight (LW) of approximately 8 kg and a monetary value of 3.89 € kg^{-1} LW. Milk had a value of 0.49 € kg^{-1} of raw milk. No other income sources were evident within the scope of the study and the allocation of the CF to milk varied by farm and year from 57% to 89% with an average of 78%.

2.2.4. *Data treatment and statistical analysis*

For the statistical analysis, farms were classified according to the three groups described above.

After testing the variables for normality, using the descriptive statistics of asymmetry and kurtosis, ANOVAs were performed to test for possible significant differences among the three groups followed by the Tukey test to evaluate significant differences between groups. IBM SPSS Statistic 23.0 for Windows (SPSS Inc., Chicago, IL, USA) was used for all analyses.

3. Results

3.1. *Inputs and outputs*

Annual inputs and outputs for each dairy system group are shown in Table 1. With regard to inputs, the values reflect that considerably less concentrates and fodder were purchased by the LPG and HPG farms than the MIG farms; no differences were found between the LPG and HPG farms. As regards outputs, the LPG farms were the least productive group (about 45%) but there were no differences between the MIG and HPG farms. No differences were found between the three farming system groups (Table 1) as far as the other variables were concerned.

3.2. *Kilogram of FPCM as a functional unit*

CF, total emissions and total soil C sequestration are presented in Table 2 for each farming system. The contribution from pollutant sources and soil C sequestration are also shown. All the variables differed according to the milk correction applied; the values for milk correction 2 were 41% lower than for milk correction 1. However, for all the variables analyzed, the type of milk correction did not affect the comparisons between groups.

CF values ranged from 2.36 to 1.76 kg CO_2e kg^{-1} FPCM for milk correction 1 and from 1.40 to 1.04 kg CO_2e kg^{-1} FPCM for milk correction 2. No differences were found between goat farming system groups (Table 2) in either of the cases.

Regarding emissions, LPG farms reported significantly higher total emissions per kilogram of FPCM and no differences were found between MIG and HPG farms. Livestock emissions were the major contributors to total emissions of all three farming system groups (contributing between 52 and 66%); livestock emissions per kilogram of FPCM were significantly higher in the LPG farms and no differences were found between MIG and HPG farms. No differences were found between the three farming system groups (Table 2) for the other variables.

Differences were found between farming system groups for the contributions of soil C sequestration. Total C sequestration was significantly lower in the MIG farms and no differences were found between LPG and HPG farms. The same pattern was found for CO_2 sequestration from crops. The values found for CO_2 sequestration from manure were significantly higher in the LPG farms than in the MIG farms (Table 2).

3.3. *Hectare as a functional unit*

MIG farms had significantly higher CF values per hectare of land use and no differences were found between LPG and HPG farms. Likewise, total emissions were significantly higher in the MIG farms than in the other two groups as a consequence of a large increase in the off-farm emissions. No differences were found between farming system groups for the rest of the variables studied (Table 3).

4. Discussion

Cattle studies are predominant in the scientific bibliography on GHG emissions from the ruminant sector but there are very few specific studies of goat systems, particularly under grazing management (Kanyarushoki et al., 2009; Robertson et al., 2015; Pardo et al., 2016). Conclusions vary widely due to differences in the productive context and the methodologies followed. As Bernués et al. (2017) stated, it is difficult to make direct comparisons between studies because of potential differences in methodological choices; therefore it is necessary to standardize the functional unit, the system boundary and the allocation method. According to these authors, it is difficult to compare the re-

Table 1
Annual inputs and outputs for each goat farming system group. In the same row different letters indicate significant differences ($P \leq 0.05$). Mean ± S.E.

	Low productivity grazing farms		More intensified grazing farms		High productivity grazing farms		F	p-values
Inputs								
Concentrates purchased (kg $ha^{-1}year^{-1}$)	273.38 ±	29.68 b	437.60 ±	58.68 a	296.46	32.08 b	4.142	**0.041**
Fodder purchased (kg $ha^{-1}year^{-1}$)	23.30 ±	12.83 b	155.99 ±	45.92 a	15.45	4.83 b	9.400	**0.003**
Fuel (liters $year^{-1}$)	772.25 ±	149.20 a	928.20 ±	306.79 a	6033.43	2703.30 a	2.218	0.148
Electricity (kwH $year^{-1}$)	4468.00 ±	1797.58 a	8503.00 ±	2863.98 a	4726.71	1952.50 a	0.925	0.421
Mineral fertilizer (kg $ha^{-1}year^{-1}$)	6.25 ±	6.25 a	86.67 ±	53.24 a	66.45	19.71 a	1.355	0.292
Outputs								
Milk, liters goat $^{-1}$	177.07 ±	35.35 b	332.67 ±	38.84 a	335.63	29.42 a	5.92	**0.015**
Kids sold $goat^{-1}$	1.00 ±	0.09 a	1.06 ±	0.13 a	0.94	0.12 a	0.30	0.746

Table 2
Carbon footprint and contribution to carbon footprint from different sources and annual C sequestration (kg CO_2 e kg^{-1} FPCM) calculated according to Petersen et al. (2013). These values have been allocated using factors based on economic value for milk and co-products (kids) derived from their monetary value at farm level. The functional units are 1 kg of fat and protein corrected milk (FPCM); results of all variables studied are presented depending on the milk correction applied: i) milk correction 1 (corrected according to Pulina et al., 2005) and milk correction 2 (corrected according to Robertson et al., 2015). In the same row different letters indicate significant differences (P ≤ 0.05). Mean ± S.E.

		Low productivity grazing farms	More intensified grazing farms	High productivity grazing farms	F	p-values
Carbon footprint	Milk correction 1	2.36 ± 0.32 a	1.97 ± 0.11 a	1.76 ± 0.13 a	2.86	0.094
	Milk correction 2	1.40 ± 0.19 a	1.16 ± 0.06 a	1.04 ± 0.08 a	2.83	0.096
Emissions	**Livestock emissions**					
	Milk correction 1	2.09 ± 0.31 a	1.16 ± 0.10 b	1.33 ± 0.15 b	6.074	**0.014**
	Milk correction 2	1.24 ± 0.18 a	0.68 ± 0.06 b	0.79 ± 0.09 b	6.107	**0.013**
	Soil emissions					
	Milk correction 1	0.35 ± 0.05 a	0.22 ± 0.04 a	0.30 ± 0.03 a	2.530	0.112
	Milk correction 2	0.20 ± 0.03 a	0.13 ± 0.02 a	0.18 ± 0.02 a	2.530	0.118
	Inputs emissions		±			
	Milk correction 1	0.74 ± 0.06 a	0.84 ± 0.02 a	0.67 ± 0.06 a	2.856	0.091
	Milk correction 2	0.44 ± 0.04 a	0.50 ± 0.02 a	0.39 ± 0.04 a	2.828	0.094
	Total emissions					
	Milk correction 1	3.17 ± 0.41a	2.22 ± 0.13 b	2.29 ± 0.17 b	4.540	**0.032**
	Milk correction 2	1.88 ± 0.24 a	1.31 ± 0.08 b	1.36 ± 0.10 b	4.600	**0.031**
C sequestration	**CO_2 sequestered from crops**					
	Milk correction 1	0.57 ± 0.12 a	0.11 ± 0.03 b	0.38 ± 0.05 a	9.129	**0.003**
	Milk correction 2	0.34 ± 0.07 a	0.07 ± 0.02 b	0.22 ± 0.03 a	9.683	**0.003**
	CO_2 sequestered from manure					
	Milk correction 1	0.24 ± 0.03 a	0.13 ± 0.01 b	0.15 ± 0.02 ab	5.360	**0.020**
	Milk correction 2	0.14 ± 0.02 a	0.08 ± 0.01 b	0.09 ± 0.01 ab	5.390	**0.011**
	Total C sequestration					
	Milk correction 1	0.81 ± 0.14 a	0.25 ± 0.04 b	0.53 ± 0.06 a	10.850	**0.002**
	Milk correction 2	0.48 ± 0.08 a	0.15 ± 0.02 b	0.32 ± 0.04 a	10.820	**0.002**

Table 3
Carbon footprint and contribution to carbon footprint from different sources and annual C sequestration (kg CO_2 e/kg FPCM) calculated according to Petersen et al. (2013). These values have been allocated using allocation factors based on economic value for milk and co-products (kids) derived from their monetary value at farm level. The functional unit is 1 ha of utilizable agricultural land. In the same row different letters indicate significant differences (P ≤ 0.05). Mean ± S.E.

		Low productivity grazing farms	More intensified grazing farms	High productivity grazing farms	F	p-values
Carbon footprint		1330.04 ± 440.62 a	8629.57 ± 4948.23 b	1249.77 ± 242.13 a	7.21	0.028
Emissions	Livestock emissions	1117.30 ± 305.46 a	4983.38± 2821.74 a	893.51 ± 149.59 a	4.17	0.075
	Soil emissions	180.79 ± 48.06 a	828.47 ± 398.40 a	206.44 ± 45.32 a	3.05	0.131
	Inputs emissions	436.13 ± 168.86 a	3683.87 ± 2134.20 b	504.44 ± 132.19 a	8.82	**0.032**
	Total emissions	1734.23 ± 519.61 a	9495.72 ± 5349.26 b	1604.39 ± 313.65 a	7.07	**0.048**
C sequestration	CO_2 sequestered from crops	404.19 ± 78.99 a	866.15 ± 401.03 a	354.62 ± 71.52 a	1.53	0.460
	CO_2 sequestered from manure	128.12 ± 36.63 a	575.68 ± 329.74 a	102.67 ± 17.22 a	4.50	0.061
	Total C sequestration	404.19 ± 78.99 a	866.15 ± 401.03 a	354.62 ± 71.52 a	1.53	0.460

sults of this study with others due to differences in the production context and in the methodologies used. However, some useful ideas can be derived from a methodological point of view.

4.1. The importance of the functional unit used

The most common functional unit used for CF calculation is the kg of fat and protein corrected milk (kg of FPCM). According to the Spanish federation of select livestock associations, (FEAGAS, 2018), the 8 main goat breeds in Spain (Florida, Majorera, Malagueña, Murciano-Granadina, Palmera, Payoya, Tinerfeña and Verata) reach values of 4.8% fat and 3.8% protein. On the other hand, according to Devendra and McLeroy (1982) goats in the tropics give values of 4.8% fat and 3.7% protein. The literature does not report any calculation of CF using a specific equation for goat's milk therefore the authors have used two equations in this study; one for sheep's milk, named milk correction 1, and another for cow's milk, named milk correction 2. When milk correction 2 is used as a functional unit, CF is 41% lower than when milk correction 1 is used (Table 2), because sheep's milk has a higher fat and protein content (7.6 and 5.5%) than cow's milk (4.8 and 2.8%) (Devendra and McLeroy, 1982). On the other hand, if sheep or cattle correction equations are used instead of goat correction equations, the emission values allocated are overestimated if sheep fat and protein values are used and underestimated if cattle values are used. Therefore it is not easy to compare results, and the methodology must be well defined, stating which correction equation has been chosen and using a goat's milk correction equation, taking into account average protein and fat values.

When CF results are expressed using efficiency metrics (such as kg of FPCM), the female productive level (generally higher in confined goats than in grazing goats) is a critical factor, as more milk production reduces the CF. Nevertheless, as Rivera-Ferre et al. (2016) observed when addressing the common global resources to mitigate GHG emissions, the use of an efficiency metric such as kg of FPCM is not the most appropriate. This is because other positive externalities with environmental or social implications should be taken into consideration such as fire prevention, enhancement of biodiversity or maintenance of local traditions, all of which are directly related to grazing. As observed in this study, using one hectare of UAL (Utilizable Agricultural Land) as a functional unit, MIG farms had a significantly higher CF per hectare compared with LPG and HPG because of a large increase in off-farm emissions (Table 3). Similar results were obtained by Robertson et al. (2015), in New Zealand, where pastoral goat farms had a significantly lower CF per hectare but a higher CF per kg of FPCM compared to intensive farms. Salvador et al. (2017), in small-scale mountain dairy farms in the Italian Alps, found that Lower Livestock Unit farms registered higher values of GHG emissions per kg of FPCM than Higher Livestock Unit farms (1.94 vs. 1.59 kg CO_2e kg^{-1} FPCM), nevertheless the situation was reversed upon considering the m^2 of Utilizable Agricultural Land as a functional unit (0.22 *vs.* 0.73 kg CO_2e m^{-2}). Likewise, Salou et al. (2017) who compared milk production systems in France, found a lower GWP per hectare in the grass-based, organic and highland systems compared with more intensified systems. This was due to the switch from grass-based feed to maize silage and concentrate feed.

4.2. Livestock intensification and climate change

The potential offered by goats, with their ability to survive in disadvantaged areas, is broadly recognized at national and international level (Mosquera-Losada et al., 2006; Rosa García et al., 2012). Moreover, ruminants have played an important role in the genesis and maintenance of landscapes (Emanuelsson, 2009). However, several previous studies on livestock GHG emissions and their relationship with different management systems advocate an intensification of animal production to mitigate the emission of GHGs (Steinfeld and Gerber, 2010; O'Brien et al., 2011; Stackhouse et al., 2012; Cohn et al., 2014; Ruviaro et al., 2014), moving away from rustic and traditional animals to specialized and highly productive breeds.

The main rationale behind this proposal is that productivity levels of the extensive systems are much lower and as consequence, emission intensities are consistently higher in these types of system (Opio et al., 2013; Gerber et al., 2013). One of the reasons why extensive systems are less productive is that animals use more energy travelling to pasture thus increasing maintenance requirements (Gill et al., 2010). The main source of emissions is methane from enteric fermentation (Zervas and Tsiplakou, 2012; Buratti et al., 2017). As grazing animals basically feed on forage (Hegarty et al., 2010; Desjardins et al., 2014), extensive systems produce more methane than intensive systems. As intensive systems commonly rely more on highly digestible concentrates and quality forage, these farming practices can reduce emissions and leave a lower CF than the less intensified systems (Foley et al., 2011; O'Brien et al., 2012; Bellarby et al., 2013; Gerber et al., 2013; Soussana and Lemaire, 2014). Therefore, intensification of production systems can be considered as an effective way to increase production and reduce GHG emission intensity (Zhuang and Li, 2017). Supposedly, this is an '*efficiency gain*'; i.e. more output with less input and less environmental impact per kg of product (Bernués et al., 2017) but this argument does not take into account that human-edible grain may be used to feed animals instead of using crop waste and pastures of marginal lands, nor does it consider that grazing animals can be important drivers of C sequestration in pasture systems, a critical ecosystem service provided by grasslands (Batalla et al., 2015).

Under the conditions established in our research and considering only total emissions, without including sequestration, it is true that the low productivity grazing (LPG) farms produce more emissions per kg of fat and protein corrected milk (FPCM) than more intensified grazing (MIG) farms. This is due to their intrinsic lower productivity. Nevertheless, emissions do not differ between high productivity grazing (HPG) and MIG (Table 2) because both models achieve an adequate level of productivity (335.63 and 332.67 L per goat respectively, Table 1). When CF values are compared in the productive models considering GHG emissions and soil C sequestration, there are no longer any differences between the three groups. This is because total net emissions are reduced by 23–26% in the grazing system when soil C sequestration is considered in CF calculations (Table 2). These results are similar to those found by Batalla et al. (2015) in sheep farming systems in northern Spain using the same methodology to estimate soil C sequestration (Petersen et al., 2013). Batalla et al. (2015) pointed out that the CF was reduced by 15% for semi-intensive systems with foreign breeds to 43% for semi-extensive systems with local breeds, when soil C sequestration was included. Salvador et al. (2017), reported a reduction from 28 to 31% in Italian mountain dairy farms when sequestration was considered, for Lower and Higher Livestock Unit farms respectively.

In grazing systems, C sequestration is an important aspect to consider due to the amount of C added to soils from grazing, C residues from crops and C from manure. In recent years, several research studies have shown that C sequestration can be maximized by using adequate management practices for livestock grazing, for example through rotational grazing management (multi-paddock systems) or with an appropriate grazing intensity according to each specific context (soil texture, precipitation or grass type) (McSherry and Ritchie, 2013; Wang et al., 2015; Stanley et al., 2018).

According to the results in this study, total C sequestration in LPG and HPG farms is 51%–70% higher than in MIG farms (Table 2). This is because LPG and HPG farms have larger surface areas. It also gives higher C values from crop residues (above and below ground), although a larger surface area only makes a significant difference in HPG farms. Soil C sequestration from manure in absolute terms has higher values in HPG (71,186 kg CO_2 e), followed by MIG (30,744 kg CO_2 e) and then by LPG (21,571 kg CO_2 e). This is mainly because there are more animals per hectare and hence more manure per hectare.

Pastoral systems provide ecosystem services such as soil C sequestration, maintenance of biodiversity or reduction of fuel biomass and enable land to be released to grow crops directly for human consumption. Due to the strong links between pasture-based livestock production and the provision of diverse ecosystem services, and according to Ripoll-Bosch et al. (2013), such services must be considered and integrated into the evaluation of GHGs emissions at farm level.

5. Conclusions

In view of the results found in this study, it would be recommendable to promote, in protected natural areas, a livestock farming model with low dependence on external inputs and, when feasible, for animals to use natural vegetation directly. Optimization of grazing resources and appropriate productivity levels per goat partly reduce the CF in grazing dairy goat farms. It is noteworthy that soil C sequestration quantification is necessary to obtain a more realistic value of the CF otherwise grazing systems would be overestimated. The results of this study show that when soil C sequestration is considered in CF calculations, differences between the less productive group and the other two groups disappear.

Although the environmental indicator CF is interesting to gather information about the contribution of livestock to GHG emissions, this indicator should be used with precaution due to the methodological difficulties involved in the calculation, particularly when determining the system's boundaries, the functional unit and when estimating C sequestration. Therefore a specific standardization formula must be drawn up for dairy goats in order to calculate the CF and build standardized models that consider the soil C sequestration of the Mediterranean farming systems.

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