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in

Ruiz R. (ed.), López-Francos A. (ed.), López Marco L. (ed.).
Innovation for sustainability in sheep and goats

Zaragoza : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 123

2019
pages 31-35

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Abstract. Sardinia (Italy) plays a relevant role on EU sheep milk production. As well as in others Mediterranean regions, contrasting dairy sheep farming systems coexist in Sardinia and an effective renovation process is needed in order to contrast the deep structural crisis. Eco-innovation of production processes and the valorisation of pasture-based livestock systems can be a key strategy to improve the farms competitiveness and to promote the typical Mediterranean dairy sheep products in a green way. For this purpose, research studies are needed in order to assess the environmental implications of Mediterranean sheep systems with a holistic and site-specific approach. The main objective of this study was to compare the environmental performances of two contrasting sheep milk production systems, by using a Life Cycle Assessment (LCA) approach. The LCA was carried out in a farm where, along ten years, a conversion from arable and irrigated crops to native and artificial pastures and a reduction of total mineral fertilizers supply occurred. The effects of the conversion on the environmental impacts were analyzed both using 1 kg of Fat and Protein Corrected Milk (FPCM) and 1 ha of surface as functional units. The LCA study highlighted that the change from a semi-intensive to a semi-extensive production system had a different effect on the environmental impacts depending on the utilized functional unit.

Keywords. Dairy sheep – Environmental impacts – Life Cycle Assessment – Functional unit.

Implications environnementales de différents systèmes de production dans une ferme de moutons laitiers de Sardaigne

Résumé. *La Sardaigne (Italie) joue un rôle important dans la production de lait de brebis de l'UE. Ainsi que dans d'autres régions méditerranéennes, des systèmes agricoles contrastés de brebis laitières coexistent en Sardaigne et un processus de rénovation efficace est nécessaire pour contrecarrer la crise structurelle profonde. L'éco-innovation des processus de production et la valorisation des systèmes d'élevage à base de pâturage peut être une stratégie clé pour améliorer la compétitivité des exploitations agricoles et pour promouvoir les produits de brebis laitières typiques de la Méditerranée. A cet effet, des recherches sont nécessaires afin d'évaluer les conséquences environnementales des systèmes méditerranéens de brebis laitières avec une approche holistique et spécifique par site. L'objectif principal de cette étude était de comparer les performances environnementales de deux systèmes contrastés de production de lait de brebis, en utilisant une approche d'évaluation du cycle de vie (ACV). L'ACV a été réalisée dans une ferme où, au cours de dix années, ont eu lieu une conversion pour passer des cultures arables et irriguées aux pâturages naturels et artificiels et une réduction de l'apport total d'engrais minéraux. Les effets de la conversion sur les impacts environnementaux ont été analysés en utilisant 1 kg de lait corrigé pour la matière grasse et les protéines (FPCM) et 1 ha de surface en unités fonctionnelles. L'étude ACV a mis en évidence que le passage d'un système de production semi-intensif à un système semi-extensif a eu un effet différent sur les impacts environnementaux en fonction de l'unité fonctionnelle utilisée.*

Mots-clés. *Brebis laitieres – Impacts environnementaux – Analyse du cycle de vie – Unité fonctionnelle.*

I – Introduction

Dairy sheep farms play a key-role in marginal rural areas of Europe, where extensive farming systems often represent the only tool for supporting local micro-economies (Porqueddu *et al*., 2017). Sardinia (Italy) is one of the leading regions for the sheep milk production: 3.2 million ewes provide a per capita annual production of about 200 kg of sheep milk per inhabitants. Geographical location of farms, specific market conditions and others external factors such as public incentive policies facilitated the development of contrasting dairy sheep farming systems, with differences in input utilization, land use and intensification level. Intensive production systems occurred especially in lowlands, where irrigated crops like maize (for silage), lucerne and hybrid forage sorghum are spread, in order to increase forage productivity. More recently, many farmers tried to reduce production's costs, through the extensification of the production system, reducing the use of concentrates, agrochemicals, agricultural machines, etc. (Porqueddu, 2008). There is not clear scientific evidence showing that extensive systems, at least at farm scale, are really preferable to more intensive one from an environmental point of view. This work is intended to serve to fill this knowledge gap, investigating with a Life Cycle Assessment (LCA) approach if and how the adoption of a low input production system may result in an effective variation of environmental impacts at farm level. In particular, the main scope of this study was to compare the environmental impacts of two contrasting sheep milk production systems carried out in the same farm in different years, considering whether 1 kg of Fat and Protein Corrected Milk (FPCM) and 1 ha of Utilized Agricultural Area (UAA) as functional units.

II – Material and methods

1. Characteristics of the two production systems

The case study was a dairy sheep farm located in Osilo (40°45'11" N and 8°38'43" E, elevation 364 m a.s.l) (Province of Sassari), North-western Sardinia. In the period 2001-2011, the farm changed its forage production system that can be assumed as "semi-intensive" and "semi-extensive" in 2001 and 2011, respectively. In 2001, the farm was characterized by a foraging system based on cereal crops (wheat and barley grain), annual forage crops (ryegrass/oat mixture, mainly) and irrigated maize for silage, and milk production was entirely sold to the dairy industry. From 2008 to 2011, the farm management changed the production strategy, destining the whole farm milk production to the on-farm manufacturing of "Pecorino di Osilo" cheese and, moreover, largely utilizing natural and artificial pastures as feed resources, valorising the role of native legumes-grasses mixtures and adopting low-input farming practices (minimum tillage, reduced use of fertilizers, etc.). Table 1 describes the characteristics of the two production systems.

2. *LCA methodological issues*

The LCA study was conducted adopting a "from cradle to gate" approach and using 1 kg of FPCM and 1 ha of UAA as functional units. The system boundaries included all inputs and outputs related to sheep milk production, and their impact allocation was performed on economic value basis. All data were organized into a Life Cycle Inventory (LCI), the process that quantifies energy and raw material requirements, atmospheric and waterborne emissions, solid wastes and other releases for the entire life cycle of a product. In summary, the LCA analysis included the amount of fodder crops and pastures consumed by flocks, after crosschecking forage production and nutritional needs based on gender, age, weight, physiological stage and production level of animals (Vagnoni *et al.,* 2015). In addition, enteric methane emissions were quantified using a detailed approach (IPCC Tier 2/3) based on Vermorel *et al*. (2008) and considering the total metabolizable energy ingested with the specific animal category diet. In order to consider a wide range of impact categories, IPCC (IPCC, 2013) evaluation method was utilized for the Carbon Footprint (CF) estimates, expressed in kg of CO2-equivalents. LCA calculation was made using LCA software SimaPro 8.1.1 (PRé Consultants, 2016).

Table 1. Main characteristics of the two different production systems adopted to the same farm in 2001 and 2011

	2001	2011
Heads (number)	340	320
Stocking rate (ewes ha^{-1})	4.6	4.6
Milk total annual production (kg)	104,234	82,214
Milk pro-capite annual production (kg ewe^{-1} $year^{-1}$)	307	257
Feed Unit for Lactation, UFL (UFL ewe^{-1} $year^{-1}$)	478	387
Pastures – grazing area (ha)	3	52
Arable land – cereals and annual forage crops (ha)	70	18
Total utilized agricultural area (ha)	73	70
Concentrate feed annual consumption (t)	105	98
Mineral N-fertilizing (kg ha^{-1})	72	8
Mineral P2O5-fertilizing (kg ha^{-1})	110	29
Irrigated maize (ha)	7	0
Irrigated lucerne (ha)	0	2.7
Milk destination	Cheese industry	On-farm cheese manufacture
Power source	Diesel generator	Electricity

III – Results and discussion

The CF of 1 kg of FPCM was quite similar in 2001 and 2011 production systems, with values equal to 2.99 and 3.25 kg CO2-eq, respectively (Figure 1a and 1b). This result seems to agree with some findings reported in literature (Gerber *et al*., 2013), where more intensive systems had a lower environmental impact per kg of product than extensive one. When the environmental impact assessment was performed using as functional unit 1 ha of UAA, the CF of the two productive systems showed relevant differences, confirming the strict positive relationship between the environmental impact of farms and the intensity level in the inputs. The 2001 productive system had the largest value of CF (5,500 kg of CO2-eq for 1 ha of UAA). On 2011, extensification led to a reduction of around 30% of the CF, relative to 1 ha of UAA (Figures 1c and 1d). The analysis conducted using 1 ha of UAA as functional unit showed that the extensive dairy farm, with a high surface area for natural pasture, has much lower environmental impacts than the more intensive production system. In this case, it appears more evident that there is a link between intensive farming, with a consequent greater consumption of inputs, and a greater environmental impact. The contribution analysis illustrates the main processes that contributed to total CF of each production system. For both functional units, “enteric methane emissions” was the most relevant process, representing 50 and 57% of the total GHG emissions, respectively for 2001 and 2011. Summarizing the percentage contributions to total CF of each feed production process, we obtained the same value for the two production systems (around 26%), with a predominant influence of purchased feed (soybean meal, protein pea and cereals grain) with respect to on-farm feed production. This suggested that the increase of the locally produced feed supply may represent a step ahead towards a more eco-sustainable sheep farming system. The percentage contributions of the other processes reflected, in general, the contrasting technological context and farm management strategy, which characterized the two farming systems, such as power source (diesel generator in 2001 and public electricity in 2011), fertiliser use and agricultural machineries supply.

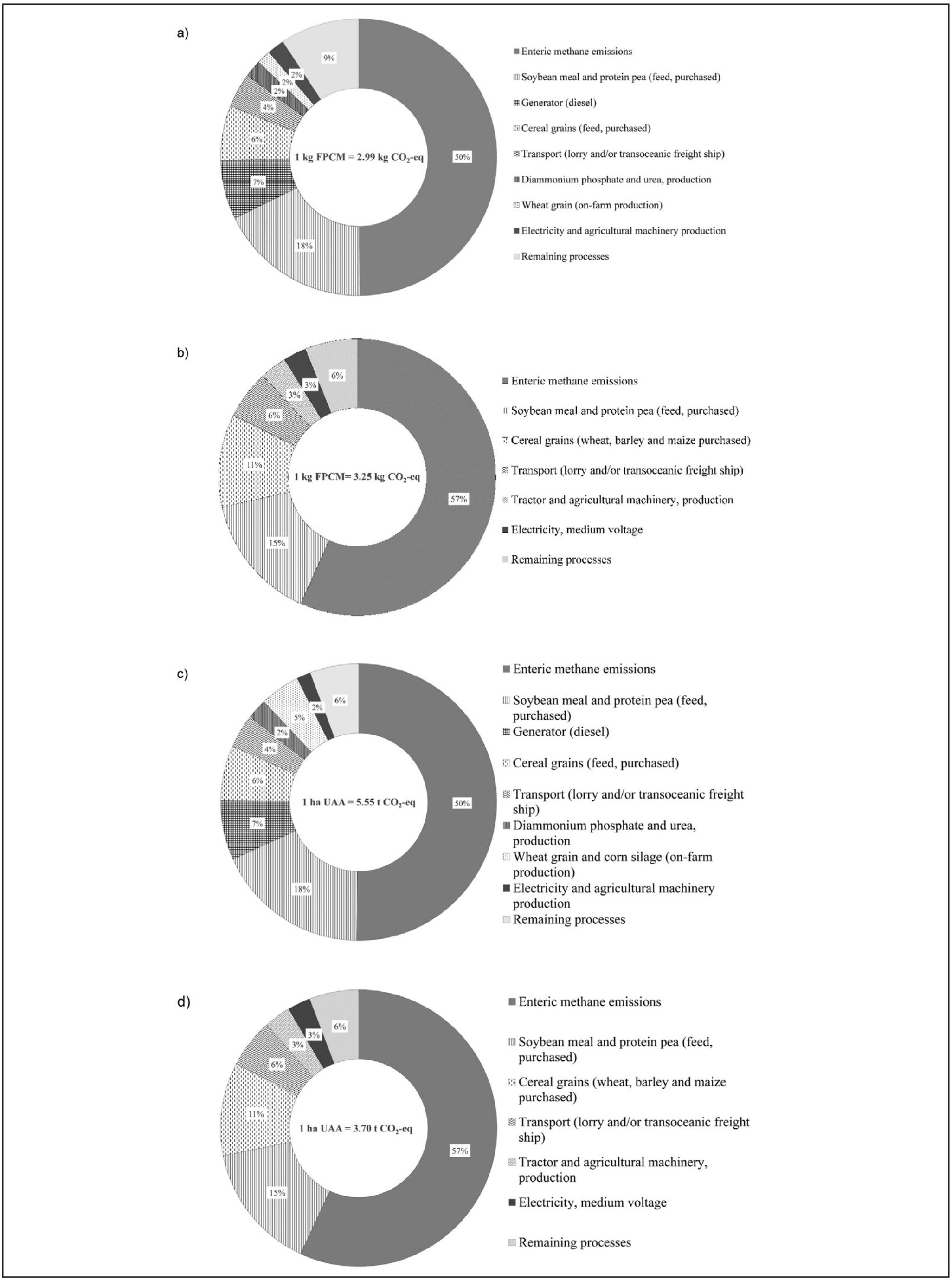

Fig. 1. Percentage contribution of processes to the total GHG emissions, for the 2001 and 2011 production systems using IPCC evaluation method and 1 kg of FCPM (a and b) and 1 Ha UAA (c and d) as functional units. The process category "Remaining processes" includes all the processes with a percentage contribution lower than 0.25% for both production systems.

IV – Conclusions

In this work, LCA approach was used for comparing dairy sheep production systems and for identifying the hotspots to improve their environmental performances. The LCA conducted with two different functional units (1 kg of Fat Protein Corrected Milk and 1 ha of Utilized Agricultural Area) led to a more objective evaluation of the environmental performances of the two productive systems, taking into account both the economic dimension and the environmental role of dairy farming systems. As functional unit, 1 Ha of UAA seems to be more descriptive and effective than 1 kg of FPCM, when LCA analysis is aimed at describing the effect of land use on the environmental performances of extensive dairy systems.

Acknowledgements

The research was funded by the Project SheeptoShip LIFE15 CCM/IT/000123 "Looking far an eco-sustainable sheep supply chain: environmental benefits and implications".

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