Environmental performances of three Sardinian dairy sheep production systems at different levels of intensity

Vagnoni E.[1*], Franca A.[2], Breedveld L.[3], Porqueddu C.[2], Duce P.[1]

[1]Institute of Biometeorology, National Research Council – CNR IBIMET, Sassari, Italy
[2]Institute for Animal Production System in Mediterranean Environment, National Research Council – CNR ISPAAM, Sassari, Italy
[3]2B s.r.l. – Mogliano Veneto (TV), Italy
*E-mail: e.vagnoni@ibimet.cnr.it

Abstract

Within the CAP "greening" reform process, the optimization of environmental performances is a crucial factor to improve the competitiveness of small and medium farms, especially in marginal rural areas. Life Cycle Assessment (LCA) is the most advanced and complete computational tool for providing a widespread knowledge on the environmental aspects associated with products or production processes. This paper illustrates an LCA study carried out to assess the environmental impacts of sheep milk production obtained in three different dairy farms located in North-Western Sardinia, Italy. The main goals of the analysis were (i) to compare the performances of three sheep milk production systems at different levels of intensity, and (ii) to identify the hotspots to improve the environmental performances of each farm. The analysis was conducted using two different functional units: 1 kg of Fat and Protein Corrected Milk and 1 ha of Utilized Agricultural Area. The life cycle was assessed "from cradle to gate", including all the input and output related to sheep breeding and using farm-specific data for year 2011. The potential impacts associated with milk production were quantified using three different impact assessment methods. In addition, some options for improving the environmental performances of each farm were identified: for all farms, changing power supply strategy; for semi-intensive and intensive farms, using locally-produced feed and increasing the use of pasture resources; for extensive and semi-intensive farms, rethinking on size and number of agricultural machineries.

Keywords: sheep milk production systems; environmental performances; LCA; competitive sheep farming.

Introduction

In the current Common Agricultural Policy reform process, eco-sustainability of production systems and global climate change effect mitigation are key priorities, which will result in increasing financial support towards a more environmentally sound agriculture. Therefore, the optimization of environmental performances is a crucial factor to improve the competitiveness of small and medium farms. Moreover, recognizing and assessing the low environmental impact of production processes could represent an added value that justifies the access to financial incentives for sustainable productions, particularly in marginal rural areas. A twofold objective can be achieved: (i) one is to reduce greenhouse gas (GHG) emissions from the agriculture sector, thus improving the environmental impact of production processes; (ii) the other is to lower production costs through the adoption of methodologies and technologies that require less energy inputs and improve productivity. Consequently, it is essential to develop effective approaches to reduce GHG emissions, and to identify the different parts of food chains where to concentrate efforts. Life Cycle Assessment (LCA) is the most advanced and complete computational tool for providing a widespread knowledge on the environmental aspects associated with products or production processes (Hayashi *et al.*, 2007). In addition, LCA is also the first step towards sustainable production systems, giving information about where environmental impacts and damages take place. This paper illustrates an LCA study carried out with the purposes of (i) comparing the environmental impacts of sheep milk production from three different dairy farms in Sardinia, Italy, characterized by different production intensity, and (ii) identifying the hotspots to improve the environmental performances of each farm.

Material and methods

Data were collected from three different dairy farms located in North-Western Sardinia, Italy. These farms were chosen since they are representative of three sheep milk production systems in the region, with different levels of intensity, as summarized in Table 1.

Table 1: Main production system characteristics of dairy farms F1 (extensive), F2 (semi-intensive), and F3 (intensive). Data are referred to year 2011.

	F 1 - extensive	F 2 – semi-intensive	F 3 - intensive
Utilized Agricultural Area (ha)	125	70	67
Heads (number)	120	320	370
Stocking rate (ewes ha^{-1})	1.0	4.6	5.5
Milk production (kg $year^{-1}$)	25000	79655	110000
Milk pro-capita annual production (kg ewe^{-1} $year^{-1}$)	208	249	297
Natural grazing area (ha)	95	52	12
Arable land – cereals and annual forage crops (ha)	30*	18	55
Concentrate feed annual consumption (t) **	1	121	204

*10% of the arable land production is used for sheep feeding, the remaining part is sold as hay and grain.
** F1 produces all concentrates on farm, F2 imports them all and F3 imports the 86%.

The methodology used to carry out the LCA study is consistent with the international standards ISO 14040-14044 (2006). The analysis was conducted using two different functional units (FU): 1 kg of Fat and Protein Corrected Milk (FPCM) and 1 ha of Utilized Agricultural Area (UAA). The use of two FU permitted to define and to combine productivity and economic results with depletion of natural resources and to conduct a more objective impact analysis taking into account the different production intensity (Haas et al., 2000). The life cycle was assessed "from cradle to gate", including all the input and output related to sheep milk production: the livestock subdivided by gender, age, physiological and production phases; the fodder and feed production, transport and consumption; the breeding operations (shearing, milking, milk cooling, health care, etc.); the fuel, energy and water consumption; the devices and agricultural machineries; the consumable items (medicines, washing detergents and all minor stable supplies). Modes and distances of all transportations within the system were also taken into account. All the resources (materials, energy, etc.) needed by each process were determined, as well as the amount of waste and emissions to soil, water and air. Most life cycle processes' data (e.g. animal performances, forage productions, fuel consumption, etc.) were collected through visits *in situ*, interviews and a specific questionnaire (farm-specific data for year 2011). The other data (e.g. methane enteric emissions, supplement chemical composition, etc.) were collected from available literature and databases (mostly Ecoinvent v. 2.2, 2004-2010). Since all three farms produced not only milk but also meat and wool, all "inputs" and "outputs" included in the LCA analysis performed using 1kg of FPCM as functional unit were partitioned (impact allocation) between milk and the other by-products, on the basis of the economic value of products (economic allocation). When co-products were obtained from the same plot (e.g. triticale-barley grain and stubble), mass-based allocation was applied. Three different evaluation methods were used: 1) IPCC (2007), which provides estimates on greenhouse gases emitted in the life cycle of products, expressed in kilograms of CO_2-equivalents with 100-year time horizon; 2) Blue Virtual Water that estimates the (virtual) water content incorporated into a product (the volume of water, expressed in l-equivalents, consumed or polluted for producing the product during the entire life cycle) (Hoekstra *et al.*, 2011); 3) Recipe, that provides a more comprehensive assessment of life cycle environmental performances, considering 17 different categories of environmental impact which are calculated and harmonized obtaining a single eco-indicator (ecopoint) (Goedkoop et al., 2012). The life-cycle analysis was performed under the following simplification conditions: farm crops were included in the analysis only when used as forage, and taking into account only the amount consumed by flocks, after crosschecking estimated and/or measured forage production and estimated nutritional needs based on gender, age, weight, physiological stage and production level of animals. Moreover, national inventories of emissions by ISPRA (2011) for CH_4 and by IPCC (2007) for N_2O were used to quantify flocks' enteric emissions. LCA calculation was made using LCA software Sima Pro 7.3.3 (PRé Consultants, 2011), which contains various LCA databases.

Results and discussion

The LCA analysis based on the three methods indicated an overall environmental impact lower in the extensive farm compared to the semi-intensive and intensive ones (Table 2). These differences were more evident using the Blue virtual water method, which highlighted that the virtual water consumed by F1 per kg of FPCM was 5-9 times lower than F2 and F3. In fact, F1 showed a very low direct water consumption, mainly due to the absence of mechanical milking and irrigation. The analysis conducted using 1 ha of UAA as functional unit showed that the extensive dairy farm with a high surface area for natural grazing and crop cultivation has much lower environmental impacts compared to the semi-intensive and intensive farms regardless of the method used.

Table 2: Main LCA results for three farm management systems (F1, extensive; F2, semi-intensive; F3, intensive) using IPCC, Blue Virtual Water and Recipe methods and two different functional units (1 kg of FPCM and 1 ha of UAA).

IPCC method (kg CO_2 eq)	**F1**	**F2**	**F3**
FU: 1 kg FPCM	1.85	2.20	2.01
FU: 1 ha UAA	432	2430	3680
Blue Virtual Water (l eq)			
FU: 1 kg FPCM	7.1	37.8	65.1
FU: 1 ha UAA	1660	41700	119000
Recipe method (eco-pt)			
FU: 1 kg FPCM	0.29	0.47	0.41
FU: 1 ha UAA	67	520	745

A detailed contribution analysis is reported in Table 3, which illustrates all processes that contributed more than 1% to the total environmental impact of all the farms, using the three different evaluation methods. Data referred to 1 ha of UAA as FU are not reported. In general, the analysis of the contributions of individual processes showed a significant role of methane enteric emissions, of machinery stock (impacts derived from their production process at factory) an use (diesel engine use), of natural pasture utilization and, in farms F2 and F3, of feed concentrates in the diet. The analysis of the environmental impacts of the intensive production system (farm F3) underlines the high impact of concentrate feed and silage and their transportation. The semi-intensive farm F2 was intermediate between some characteristics of extensive (F1) and intensive (F3) farms. The incidence of contribution of each process changed according the evaluation method utilized. For example, the methane enteric emission represented an average 43% of total impacts in IPCC method (which considers the processes in order to their contribution to global warming), but only 10% in Recipe method (which includes others 15 impact categories in addition to global warming). This confirms that the adoption of the three different evaluation methods, offering a multiple analysis perspective, allowed to a more comprehensive assessment. The analysis of contributions indicates strengths and weaknesses of each dairy farm system. For instance, equipment contribution was very significant in F1 and less in F3. On the other side, sheep diet gave a great contribution especially in F3, where the self-produced feed was very low. Some options for improving the environmental performances of each farm were identified: for all farms, changing power supply strategy; for semi-intensive and intensive farms, using locally-produced feed and increasing the use of pasture resources; for extensive and semi-intensive farms, rethinking on size and number of agricultural machineries.

In conclusion, the LCA has revealed to be an interesting tool that can be applied to evaluate and to optimize the environmental performances of dairy sheep farms. But, for a more systematic interpretation leading to science-based decisions, is really important to enhance the knowledge about a Mediterranean database with site-specific emission and characterization factors which should be used in environmental hotspots (e.g. methane enteric emissions, synthetic fertilizers production and distribution, supplements production, etc.).

Table 3: Contribution of processes to the total environmental impact for all farms, using the three evaluation methods (functional unit 1 kg of PFCM). Processes with contributions lower than 1% in all the farms for the three methods are excluded.

Process	**IPCC**			**Recipe**			**Blue Virtual Water**		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	
Methane enteric emissions	49%	43%	37.5%	15%	10%	9%	-	-	
Electricity, medium voltage	14%	5%	3%	8%	2%	1.5%	21%	2%	
Diesel engine use	20%	5.5%	6%	14%	3%	4%	8%	-	
Agricultural machinery, production	6%	2%	3%	4%	1%	-	14%	1%	
Tractor, production	4%	2%	2%	3%	1%	-	8%	-	
Natural grassland	2%	0.5%	0.3%	31%	8%	9%	-	-	
Barley seed for sowing	1%	-	-	1%	-	-	26%	-	
Ryegrass seed for sowing	-	-	2%	-	-	1%	-	-	
Soy seed for concentrate feed	-	6%	6%	-	15%	15%	-	5%	
Maize grain for concentrate feed	-	10%	2%	-	9%	2%	-	3%	
Wheat grain for concentrate feed	-	3%	5%	-	2%	4%	-	8%	
Sunflower for concentrate feed	-	1%	1.5%	-	2%	3.5%	-	3%	
Hay by grassland	0%	0.5%	-	2%	8%	-	-	-	
Barley-oats-clover, grazing	-	-	-	15%	-	-	-	-	
Barley-oats-clover, hay	-	-	-	2%	-	-	-	-	
Clover-ryegrass, grazing	-	-	5%	-	-	12%	-	-	
Clover-ryegrass - hay	-	-	4%	-	-	12%	-	-	
Triticale, stubble	-	-	1%	-	-	9%	-	-	
Urea	-		2%	-		1%	-	-	
Pyretroid-compounds	-	-	-	-	-	-	-	-	
Veterinary pharmaceuticals	-	-	-	-	-	-	-	20%	
Transport, transoceanic freight sheep	-	2%	2%	-	1%	1%	-	-	
Remaining processes (more than 150 other processes included)	4.0%	19.5%	17.7%	5%	38%	16.0%	23%	58%	

References

Goedkoop M.J., Heijungs R., Huijbregts M., De Schryver A., Struijs J. and Van Zelm R. (2012) Recipe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition (revised). Report I: Characterisation. July 2012.

Haas G., F. Wetterich and Geier U., 2000. Life cycle assessment framework in agriculture on the farm level. International Journal of Life Cycle Assessment. 5, 6: 345-348.

Hayashi K., Gaillard G. and Nemecek T. (2007) Life cycle assessment of agricultural production systems: current issues and future prespectives. In: International Seminar on Technology Development for Good Agriculture Practice in Asia and Oceania, 98-109.

Hoekstra A.Y., Chapagain A.K., Aldaya M.M. and Mekonnen M.M. (2011) The water footprint assessment manual: Setting the global standard. Earthscan, London, UK. 224 pp.

IPCC (2007) Climate Change 2007, IPCC Fourth Assessment Report, Geneva.

ISO (2006) ISO 14040-14044. Environmental management—Life cycle assessment: Principles and

framework; Requirements and guidelines. CEN (European Committee for Standardisation), Brussels.
ISPRA (2011). Emissioni nazionali in atmosfera dal 1990 al 2009. Roma. 80 pp.
PRé Consultants (2011). Software LCA SimaPro 7.3., Netherlands.