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Transition among different production systems in a Sardinian dairy sheep farm: Environmental implications

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ABSTRACT

Sardinia (Italy) plays a relevant role on EU sheep milk production. In Sardinia, as well as in other Mediterranean regions, there is a range of different dairy sheep farming systems and an effective renovation process is needed to tackle the deep structural crisis of the sector. The 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 environmental sustainability of the typical Mediterranean dairy sheep products. For these reasons, research studies based on holistic and site-specific approaches are needed to assess the environmental implications of Mediterranean sheep systems. The main objective of this study was to compare the environmental performances of two contrasting sheep milk production systems through a Life Cycle Assessment (LCA) approach. The LCA was carried out on a farm where changes in land use (from arable and irrigated crops to native and artificial pastures) occurred over a 10-year period, in conjunction with a reduction of total supply of mineral fertilizers. The analysis was performed using IPCC and ReCiPe methodologies, and a functional unit of 1 kg of Fat and Protein Corrected Milk (FPCM). The LCA analysis showed that the change from semi-intensive to semi-extensive production system had only a slight effect on the overall environmental performances of 1 kg FPCM, due to the dominant impact of enteric fermentation in both systems. The Carbon Footprint was on average 3.12 kg CO_2-eq per kg FPCM and the average score of the ReCiPe Endpoint was 461 mPt per kg FPCM. Methane enteric emissions and the use of imported soybean meal were identified as the main environmental hotspots.

1. Introduction

The dairy products scenario described by the last OECD-FAO (2015) baseline projection attributes to the sheep sector the most dynamic trend with an expected production increase of 23% during the period 2014–2024. Europe, with a contribution of about 35%, is the second continent in the world for sheep milk production, after Asia that contributes for about 44%. Considering the annual production of sheep milk per inhabitant in the mid-2000s, Europe is by far the world's biggest producer: 4.1 kg per inhabitant compared to an average worldwide production of 1.4 kg per inhabitant (FAOSTAT, 2014). The European sheep milk production is concentrated in Central and Southern regions (Czech and Slovak Republics, Hungary, Romania, Greece, France, Spain and Italy) where the dairy sheep farming plays a crucial role in cultural, economic and ecological terms, mainly in marginal rural areas. Structural data indicate that Sardinia (Italy) is among the leading regions for the sheep milk production: 3.2 million ewes and 14,000 dairy sheep farms (Anagrafe Nazionale Zootecnica, 2016) provide about 330,000 t year^{-1} of milk, and 201.2 kg of milk per capita (ISTAT, 2012). In fact, 25% of total EU-27 sheep milk production came from Sardinia (Rural Development Programme of Sardinia – RDP, 2014–2020). These numbers explain why the dairy sheep breeding, driven by the export of Pecorino Romano PDO cheese, represents one of the main economic sectors of Sardinia. In Sardinia, as well as in other Mediterranean regions, there is a range of different dairy sheep farming systems, with differences in land use and input and intensification levels. These differences depend on a number of factors ranging from geographical location and specific market conditions to public incentive policies and local or global market trends (Biala et al., 2007). In the 80s, programs and actions for increasing farm productivity led to the development of intensified production systems in Sardinian lowlands, where the availability of irrigation water contributed to the spread of highly-yield forage crops like maize (for silage), lucerne and hybrid forage sorghum (Fois et al., 2001). Later, when the Sardinian dairy sheep farming sector suffered a deep structural crisis due to the collapse of Pecorino Romano PDO cheese price in the early 2000s, many

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farmers, looking for new strategies to reduce production costs, decided to overall extensify their production systems (i.e. low use of concentrate feeds, agrochemicals, agricultural machines, etc.) (Porqueddu, 2008). Now, the greening process of agriculture and livestock supply chain, supported by EU climate change policies and driven by the increasing demand of environmental-friendly agri-food products, puts additional emphasis on the importance of the environmental implications of production systems into marketing and production farming strategies. In this scenario, the Sardinian dairy sheep sector and the whole Mediterranean livestock supply chain can find new opportunities to improve their competitiveness through the eco-innovation of production processes and the valorisation of typical livestock products. Therefore, more research is needed in order to i) assess and improve the environmental performances of dairy sheep systems using a comprehensive approach (Vagnoni et al., 2015), and ii) enhance our understanding of the relationship between sheep farming and climate change (Marino et al., 2016; Wiedemann et al., 2015). FAO (2006a) showed several differences in greenhouse gases (GHG) emissions from small ruminant sector, according to the geographical regions, the agro-ecological zones and the grassland/mixed-based production systems. Regarding milk production, Africa and Asia were identified as the bigger GHG emitters per kg of milk, thus suggesting that the high productivity of most intensive farming systems adopted in the industrialized countries would increase the environmental performances (Opio et al., 2013). On the other hand, there is no clear scientific evidence that extensive systems, at least at farm scale, are preferable to more intensive ones from an environmental point of view. Several studies focused on complex processes that affect yield, resources consumption and emissions, showing that extensive farming systems determine lower environmental impacts than intensive systems, (Bailey et al., 2003; Casey and Holden, 2006; Haas et al., 2001; Nemecek et al., 2011; Vagnoni et al., 2015). Extensive agriculture may help in mitigating some negative environmental impacts caused by intensive livestock systems, such as consumption of fossil energy resources, demand for macroelements, global warming potential, loss of biodiversity, degradation of soil quality (Biala et al., 2007). On the other side, some studies showed that the introduction of various low-input techniques, i.e. manure fertilisation, mechanical weeding, no-till agriculture and so on, can have the opposite effect (Basset-Mens and Van Der Werf, 2005; Brentrup et al., 2004; Michael, 2011). This work was conducted with the main aim of contributing to fill in this knowledge gap. In particular, the specific objective of this study was to compare the environmental impacts of two contrasting sheep milk production systems used in the same farm during two different years through a Life Cycle Assessment (LCA) approach (de Boer, 2003; Hayashi et al., 2006).

2. Methods

2.1. 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 terms of flock size and total Utilized Agricultural Area (UAA) (Table 1), the farm belongs to the most common sheep farming system in Sardinia. As reported by Idda et al. (2010), about 65% and 47% of Sardinian dairy sheep farms has a number of heads ranging from 100 to 500 and a total UAA in the range 30–100 ha, respectively. The climate is Mediterranean with an average annual rainfall amount of 550 mm, and monthly mean temperatures ranging from 10 to 26 °C. Data refer to two years, 2001 and 2011, when two different farming systems were implemented. Primary data, collected using a specific questionnaire, derived from farm records, several visits in situ and farmer interviews. In 2001, the farm was characterized by a forage system based on cereal crops (wheat and barley grain), annual forage crops (ryegrass/oat mixture, mainly) and irrigated maize for silage. From 2008–2011, a radical change occurred in the farm management strategy, to face the very low sheep milk price payed by the Sardinian cheese industries that seriously threatened the farm profitability. Therefore, the whole farm milk production was destined to on-farm cheese manufacturing, instead of cheese industry. In particular, the farm produced “Pecorino di Osilo” cheese, which is included in the list of typical Italian agri-food products (18/07/2000 Ministerial Decree of the Italian Ministry for Agricultural, Food and Forestry). In addition, with the aim of reducing the production costs, the farm management moved to an extensification of forage production, with a larger use of natural and artificial pastures, valorising the role of native legume-grass mixtures and adopting low-input farming practices (minimum tillage, reduced use of fertilizers, etc.). Although there were considerable similarities between the two production systems (for example, number of heads, stocking rate, total UAA and concentrates consumption, see Table 1), the 2001 production system was mainly characterized by the irrigation of maize crop (7 ha), a large arable land area (73 ha) and a large use of mineral fertilizers (182 kg ha^{-1}). The feed efficiency ratio, calculated dividing the Net Energy Intake (NEI, Mcal ewe^{-1} year^{-1}) by the Dry Matter intake (kg DM ewe^{-1} year^{-1}), resulted in different values between the two years: 1.58 and 1.47 Mcal NEI kg DM^{-1} in 2001 and 2011, respectively. On the other hand, considering the individual production of milk corrected for fat and protein content (Fat and Protein Corrected Milk, FPCM), the dairy efficiency ratio was always higher in 2001 compared to 2011, when expressed in both Mcal of NEI and kg of DM ingested units (0.37 kg FPCM Mcal^{-1} of NEI and 0.59 kg FPCM kg^{-1} of DM vs 0.34 kg FPCM Mcal^{-1} of NEI and 0.50 kg FPCM kg^{-1} of DM^{-1}, respectively). Moreover, in 2011, 75% of the total UAA was destined to native and artificial pastures, on-farm maize production was abandoned and total mineral fertilizers supply was strongly reduced (about 80% less). At the same time, the farm no longer carried out the production of selected rams that, until 2001, represented an additional farm output. Starting from these features and focusing on farm forage production, the farming systems can be assumed as “semi-intensive” and “semi-extensive” in 2001 and 2011, respectively.

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

	2001	2011
Heads (number of mature ewes)	340	320
Stocking rate (Livestock Unit ha^{-1})	0.46	0.46
Milk total annual production (kg)	104,234	82,214
Milk pro-capite annual production (kg ewe^{-1} year^{-1})	307	257
Milk fat content (g 100 ml^{-1})	6.4	5.3
Milk protein content (g 100 ml^{-1})	5.6	5.2
Fat and Protein Corrected Milk (FPCM), pro-capite annual production (kg ewe^{-1} year^{-1})	303	227
Net Energy Intake, NEI (Mcal ewe^{-1} year^{-1})	812	657
Dry Matter (DM) intake (kg DM ewe^{-1} year^{-1})	515	448
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 P_2O_5-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