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Parameters affecting the environmental impact of a range of dairy farming systems in Denmark, Germany and Italy

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ABSTRACT

The environmental impact of 12 dairy farms in Denmark, Germany and Italy was evaluated using an LCA approach and the most important parameters influencing their environmental sustainability were identified. The farms represent different production methods (organic vs. conventional), summer feeding systems (confinement vs. pasture) and annual production levels (6275–10,964 kg ECM cow^{-1}). There was large variability in stocking rates (1.1–11.0 LU ha^{-1}) among farms, which has a major impact on the production per unit area of farmland, on feed self-sufficiency and on farm surplus of nitrogen. The proportion of grassland on farmland used for forage production or pasture varied from 0 to 100%. The lowest global warming potential (GWP), acidification, eutrophication and non-renewable energy use were achieved by the German pasture-based system, followed by the Danish organic dairy system and the very intensive Italian farming system with very similar environmental impact values. However, a sensitivity analysis showed that when emissions relating to direct land use change of soybean production were included in the assessment, the GWP changed considerably for the conventional farms due to the inclusion of conventional soymeal in the feed concentrate. There were strong and positive correlations between the four impact categories, and overall the results indicate that improving greenhouse gas emissions would improve the general environmental sustainability of the dairy farm. The land occupation was lowest in the farms with the highest stocking rate. The organic Danish farms had the lowest impact on biodiversity loss, which in general was positively influenced by the share of grassland in the system. A high proportion of grassland also had a significant positive effect on GWP, acidification and energy use. The other feature that mainly improved the environmental impact was the feed efficiency of the dairy cows, which was negatively correlated with GWP, acidification and eutrophication. We found no relation between the environmental impact and the milk production per cow or the stocking rate at the farm. However, due to the limited number of observations (only 12 farms were assessed), the results of the correlation analyses should be handled with care. There was also large variation in the relative contributions from on- and off-farm activities among farms and for the different impact categories, showing the importance of a holistic approach and the difficulties in evaluating a farming system both in a product and area-based perspective.

1. Introduction

Production of milk is an example of an agricultural activity that causes adverse environmental side effects, such as emission of greenhouse gases and nutrient enrichment in surface water (Thomassen et al., 2008). In the future, dairy producers will have to meet tighter environmental regulations including limits on greenhouse gas (GHG) emissions and noxious gaseous emissions such as ammonia (NH_3), and stricter nutrient management regulations to control diffuse pollution from nitrate (NO_3) leaching and phosphate (PO_4^{3-}) run-off (O'Brien et al., 2012). Milk production systems vary across Europe, ranging from lowland to highland-based and from extensive to intensive. Increased intensification has exacerbated environmental impacts and the planned removal of the European Union (EU) milk quota system in 2015 (Yan et al., 2011) is expected to result in an increase in milk output and

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decline in milk price, which presumably will lead to an acceleration of the processes of intensification and specialization (O'Brien et al., 2012). In situations where land availability is a major impediment, producers may decide to adopt alternative production strategies such as confinement systems using a Total Mixed Ration (TMR). In order to be able to devise the best strategy to cope with the new demands, the most efficient and environmentally friendly dairy systems and the parameters affecting these need to be identified. In the last ten years the Life Cycle Assessment (LCA) method has been used in several studies to assess the environmental impact of different milk production systems across Europe, especially for the comparison of organic and conventional systems (Cederberg and Mattsson, 2000; de Boer, 2003; Thomassen et al., 2008) or simply to evaluate the environmental performance of milk production on a typical dairy farm (Castanheira et al., 2010; Müller-Lindenlauf et al., 2010; O'Brian et al., 2012). Not least when discussing the effect of intensification and change in land use is it important to use methods that go beyond the dairy farm and include the off-farm activities, as illustrated by Kristensen et al. (2011). In a strategic perspective it is important to estimate the environmental impact for several categories and also to address the correlation between these categories and the different management choices of the dairy production systems. Therefore the aim of the present paper was to evaluate the environmental impact of different dairy farming systems across Europe and identify the parameters that most strongly affect the environmental performances for six impact categories of strategic importance for the dairy farmer.

2. Materials and methods

2.1. Life cycle assessment

Life Cycle Assessment (LCA) is a compilation and appraisal of the inputs, outputs and environmental impacts of a production system throughout its life cycle (Guinee et al., 2002). According to ISO standards (ISO, 2006a,b), an LCA consists of four distinct phases: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment and (4) interpretation.

2.1.1. Goal and scope definition

The goal of this study was to assess the environmental impact of milk production of different farming systems and to identify the weaknesses and the strengths of the different farming choices and strategies with the purpose of mitigating the environmental pressure.

The analysis included the life cycle required for the production of raw milk from the production stage of inputs to the products leaving the farm gate, i.e. excluding transport or processing of raw milk. For each dairy farm, a "cradle-to-farm-gate" LCA was performed. All the processes related to the on-farm activity (i.e. forages and crop production, energy use, fuel and electricity use, manure and livestock management) and related emissions were taken into account. Emissions and energy consumption from off-farm activities like production of fertilizer and pesticides, fodders and bedding materials, feed concentrate, electricity and fuel, and breeding of replacement animals were included in the estimation. Transport associated with the production of purchased feed (both commercial feed and roughages) and bedding material was included.

The functional unit used was kg energy corrected milk (ECM) (Sjaunja et al., 1990): kg ECM = kg milk*(0.25 + 0.122 * Fat% + 0.077 * Protein%) delivered to the dairy at the farm gate.

For the dairy farm the main focus is on milk production, while the meat generated from surplus calves and culled dairy cows is an important co-product (IDF, 2010). When analysing multifunctional processes the choice of allocation method is a required step in order to partition the environmental impact into the co-products generated by the system. A biological allocation, based on the feed energy required to produce the amount of milk and meat at the farm and developed by IDF (2010) was used.

2.1.2. Inventory analysis

The inventory comprised annual data from 12 dairy farms: five from Denmark (DK), two from Germany (GER) and five from Italy (IT). The farms were chosen as being representative for different milk yields and stocking rates, expressed in livestock units (LU) per unit area of farmland. Two of the five Danish (DK-1 and DK-2) farms were organic. The two German farms differed in their summer feeding systems (confinement vs. pasture), while all Italian farms used confinement feeding. The data for the Danish farms were based on intensive registration, while the data used for the GER and IT systems were collected from interviews with the farmers.

Total on-farm estimated emissions included fuel combustion, enteric fermentation from the cows, manure management (storage and handling including field application) and emissions that occur during the application of chemical fertilizers and urine/faecal deposition during grazing. The methods applied and the emission factors used are shown in Table 1.

Carbon dioxide (CO_2) emissions related to energy consumption (combustion of fossil fuels and electricity use) were estimated on the basis of the amount of diesel (litres) and electricity (kWh) used for farm operations. Emissions from livestock respiration are part of a rapidly cycling biological system, where the plant matter consumed is itself created through the conversion of atmospheric CO_2 into organic compounds. Since the emitted and the absorbed quantities are considered to be equivalent, livestock respiration is not considered a net source under the Kyoto Protocol (Steinfeld et al., 2006). Methane (CH_4) emissions from enteric fermentation were calculated according to the Tier 2 IPCC (2006a) method that is based on the dry matter intake (DMI) of the herd. CH_4 emissions from stored manure were calculated on the basis of IPCC guidelines following the Tier 2 method (IPCC, 2006a). The amount of manure handled within a system is based on the daily number of LU housed in each system and on pasture. Methane is also released from manure deposited by animals on pasture and this was estimated using the IPCC (2006a) method. Calculations for direct nitrous oxide (N_2O) emissions from manure storage were based on excretion of nitrogen (N) given as the difference between total N intake (calculated as the dietary dry matter intake and the N content of the diet) and the N output in products (meat, milk). The emission factors used are those proposed by IPCC (2006a) for solid manure and liquid slurry storage systems. Indirect emissions of N_2O from manure storages, which are mainly due to volatilisation of ammonia (NH_3), were estimated using the EF value according to IPCC (2006a).

Direct and indirect N_2O emissions occur also at field level after the application of fertilizer in organic and inorganic forms. Direct N_2O emissions were estimated from the inputs of nitrogen in the form of mineral and organic fertilizers, crop residues and N mineralization as suggested by the IPCC (2006b) Tier 1 method. The IPCC methodology was also used to compute the direct N_2O emissions that occur during the grazing period and likewise were the indirect N_2O emissions.

Nitrogen emissions from manure storage were estimated by multiplying the amount of nitrogen excreted by the emission factors proposed by IPCC (2006a), and in accordance with Castanheira et al. (2010) they took entirely the form of NH_3 volatilization. The volatilization of nitrogen in the forms of NH_3 and NO_x that occur during the application of organic and mineral fertilizers was estimated using the default emission factors indicated by Tier 1 in the EEA (2009) guidebook. The two main N inputs to agricultural land