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Benchmarking the environmental performance of specialized milk production systems: selection of a set of indicators

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ABSTRACT

Dairy production across the world contributes to environmental impacts such as eutrophication, acidification, loss of biodiversity, and use of resources, such as land, fossil energy and water. Benchmarking the environmental performance of farms can help to reduce these environmental impacts and improve resource use efficiency. Indicators to quantify and benchmark environmental performances are generally derived from a nutrient balance (NB) or a life cycle assessment (LCA). An NB is relatively easy to quantify, whereas an LCA provides more detailed insight into the type of losses and associated environmental impacts. In this study, we explored correlations between NB and LCA indicators, in order to identify an effective set of indicators that can be used as a proxy for benchmarking the environmental performance of dairy farms. We selected 55 specialised dairy farms from western European countries and determined their environmental performance based on eight commonly used NB and LCA indicators from cradle-to-farm gate. Indicators included N surplus, P surplus, land use, fossil energy use, global warming potential (GWP), acidification potential (AP), freshwater eutrophication potential (FEP) and marine eutrophication potential (MEP) for 2010. All indicators are expressed per kg of fat-and-protein-corrected milk. Pearson and Spearman Rho's correlation analyses were performed to determine the correlations between the indicators. Subsequently, multiple regression and canonical correlation analyses were performed to select the set of indicators to be used as a proxy. Results show that the set of selected indicator, including N surplus, P surplus, energy use and land use, is strongly correlated with the eliminated set of indicators, including FEP ($r = 0.95$), MEP ($r = 0.91$), GWP ($r = 0.83$) and AP ($r = 0.79$). The canonical correlation between the two sets is high as well ($r = 0.97$). Therefore, N surplus, P surplus, energy use and land use can be used as a proxy to benchmark the environmental performance of dairy farms, also representing GWP, AP, FEP and MEP. The set of selected indicators can be monitored and collected in a time and cost-effective way, and can be interpreted easily by decision makers. Other important environmental impacts, such as biodiversity and water use, however, should not be overlooked.

1. Introduction

Dairy products are important protein sources in human diets. Around 57% of the protein content of an average European diet consists of livestock products, of which about one third is milk-derived (FAOSTAT, 2013). The global demand for milk products is expected to increase further due to population growth, rising incomes and on-going urbanization (FAO, 2006).

Dairy production, however, has a major impact on the environment. The global dairy sector, producing both milk and meat, for example, is responsible for about 30% of the anthropogenic greenhouse gas (GHG) emissions from livestock (Gerber et al., 2013). Dairy production across the world is shown to contribute also to eutrophication, acidification, loss of biodiversity, and use of resources, such as land, fossil energy and water (de Vries and de Boer, 2010). The European livestock sector, for example, is responsible for more than 90% of the total emission of ammonia in the European union, and the dairy sector is one of the major contributors (Eurostat, 2015). Production of one kg of milk, furthermore, requires about 2.3–5.3 MJ of fossil energy (Upton et al., 2015).

At present, several environmental indicators are adopted to quantify and benchmark the environmental performance of dairy

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production systems, and to gain insight into potential improvement strategies. These environmental indicators are generally derived from a nutrient balance approach or a life cycle assessment (Oenema et al., 2003; Thomassen and de Boer, 2005; Yan et al., 2011).

A nutrient balance (NB) computes the difference in nutrients entering and leaving a system (Oenema et al., 2003), and allows computation of environmental indicators, such as nutrient use efficiency or nutrient loss per ha of land. An NB generally focusses on the nutrients nitrogen (N) and phosphorus (P), because these are the major nutrients that limit crop growth, and their losses can cause environmental problems (Oenema et al., 2003; Gourley et al., 2012). An NB of a dairy production system generally is computed at farm level. Indicators derived from an NB at farm level, however, do not include nutrient losses related to the production of farm inputs, such as purchased concentrates. Mu et al. (2016) demonstrated that an NB at chain level (i.e. cradle-to-farm gate) should be used to benchmark nutrient losses of dairy systems when differences in on-farm losses between systems are small, and pre-farm losses related to e.g. production of purchased concentrates, are relatively important.

Although environmental indicators derived from an NB appear to be useful to gain insight into the nutrient losses to the environment, generally they do not specify the type of losses, nor the environmental impact associated with those losses, such as the impact on acidification or climate change. Furthermore, a NB neglects certain environmental impact categories, such as the use of natural resources like fossil energy or land (Thomassen and de Boer, 2005).

Life cycle assessment (LCA) is an internationally accepted and standardized method (ISO 14040, ISO 14041, ISO 14042, ISO 14043) that quantifies the potential environmental impact related to emissions of pollutants to air, water and soil, and the use of resources during the entire life of a product. Thus, contrary to an NB approach, an LCA specifies the type of losses, as well as the associated environmental impact. Over the past few years the number of LCAs on dairy products have increased enormously (e.g. Cederberg, 1998; Thomassen and de Boer, 2005; Yan et al., 2011). However, studies suggested that collection of data required to perform an LCA appears difficult and is more time consuming than, for example, performing an NB (Thomassen and de Boer, 2005).

To benchmark the environmental performance of large groups of dairy production systems, there is a need for a set of sustainability indicators that does not require an excessive amount of data, and provides insights into the wider environmental impact of a system (Bélanger et al., 2012). Exploring correlations between various indicators can help to identify such a set of indicators (Lebacq et al., 2013). Previous studies have mainly focused on correlations between indicators within LCA (Berger and Finkbeiner, 2011; Laurent et al., 2012; Röös et al., 2013). Berger and Finkbeiner (2011), for example, analysed correlation between several environmental indicators derived from an LCA on a hundred different materials (i.e. grouped into four categories 1) ore, metal, alloys; 2) monomers and polymers; 3) organic intermediates; 4) inorganic intermediates). They concluded that to compare the environmental performance of these materials, the number of indicators can be reduced because of strong correlations between several of the resource-oriented indicators. Laurent et al. (2012) analysed correlations between the carbon footprint and thirteen other LCA impact categories of about 4000 different products and concluded that solely relying on the carbon footprint as environmental indicator could result in overlooking other important environmental impacts. Röös et al. (2013), however demonstrated that the carbon footprint generally can act as an indicator for acidification and eutrophication potential of different types of meat (i.e., pork, chicken and beef). Results are explained by the importance of nitrogen losses, contributing to both eutrophic and acidifying substances as well as to greenhouse gas emissions in the form of nitrous oxide.

So far, no study examined correlations between environmental indicators within dairy production, or included indicators derived from an NB. The purpose of our study, therefore, is to explore correlations between NB and LCA indicators, in order to identify an effective set of indicators that can be used as a proxy for the environmental performance of dairy systems. Such a set of indicators can be used, for example, to benchmark dairy farms.

2. Material and methods

2.1. Data

To identify an effective set of indicators to benchmark the environmental performance of dairy farms, we used farm data from Dairyman. Dairyman was a project in the INTERREGIVB program co-funded by the European Regional Development Fund that aimed to improve regional prosperity through better resource utilization on 113 dairy farms and stakeholder cooperation (Dairyman, 2010).

When exploring correlations between environmental indicators, we should avoid using data from contrasting production systems, because systematic differences in environmental impacts between systems bias the correlation analysis. We therefore selected 55 specialised dairy farms from Dairyman and determined their environmental performance using different indicators for 2010. We defined specialised farms as farms that have less than 5% non-dairy purpose animals, and less than 10% of their agricultural area in use for non-dairy purpose activities. The amount of energy, land and fertilizers used for non-dairy purposes was based on farmers' estimate and excluded from the data set. These 55 dairy farms are from different countries and regions (i.e. Netherlands, Ireland, Belgium (Flanders, Wallonia), France (Brittany), Germany (Baden, Württemberg) and Luxembourg) and differ in farm characteristics (Table 1).

2.2. System boundaries

Fig. 1 illustrates the system boundaries for the NB and LCA approach. For both approaches, system boundaries are from cradle-to-farm gate. For the NB, we included all on-farm activities as well as the production of purchased feed products, but production of other farm inputs were excluded because their contribution to nutrient losses was assumed to be negligible (Mu et al., 2016). In case of LCA, we considered on-farm processes, e.g. manure management, milk and feed production, and off-farm processes, e.g. fertilizer and feed production. Pesticides and water usage were not considered due to lack of data. Capital goods (buildings and machinery) were also excluded because their contribution to the environmental impact of dairy production is assumed to be low (Cederberg, 1998).

2.3. Nutrient balance

In this study, we used the method of Mu et al. (2016) to estimate N and P surpluses at chain level for each of the 55 specialised dairy farms. We first determined a NB at farm level, which equals the difference in nutrients entering and leaving the farm. Computation of a farm level NB requires data about the quantity and nutrient content of farm inputs and outputs, and data on stock changes of e.g. concentrates, roughages, animals and fertilizers on the farm. We calculated net inputs or net outputs of products that were both purchased and sold, such as animals. For the case of manure, we subtract manure outputs from the fertilizer input. The chain level NB was subsequently calculated by summing up the NB at farm