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Environmental impacts of dairy system intensification: the functional unit matters!

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ABSTRACT

In the current context of the end of dairy quotas, the increasing size of dairy farms and the expected growth in food demand, European dairy production systems are facing major challenges. The aim of this study was to assess environmental impacts of dairy system intensification to identify production systems that combine high productivity and low environmental impacts. We used the concept of the Technological Management Route, i.e. a logical set of technical options designed by farmers, to describe the diversity of milk production systems in France. Life Cycle Assessment was used to estimate impacts of these systems according to two functional units: t milk and hectare of total (on- and off-farm) land occupied. Dairy system intensification has three major effects: i) an increase in all impacts when expressed per hectare, ii) a decrease in eutrophication and land occupation per t milk, and iii) no clear effects on other impacts when expressed per t milk. The two first effects are due mostly to the switch from grass-based feed to maize silage and concentrate feed when intensifying production systems. Furthermore, the choice of functional unit leads to radically different conclusions. Using only a mass-based functional unit, which is predominant in current life cycle assessment practice, does not provide a balanced view of the impacts of intensification and could mislead decision makers in identifying promising dairy systems. More generally, current LCA practice seems largely blind to the negative environmental consequences of agricultural system intensification, as revealed by the area-based functional unit. Therefore, we recommend the use of both mass-based and area-based functional units in life cycle assessments of agricultural goods.

1. Introduction

Agricultural intensification is defined as increased production of agricultural commodities per unit of inputs, which may be labour, land, time, fertiliser, seed, feed, animals or cash (FAO, 2004). As land is the ultimate limiting input for agricultural production, agricultural intensification is most often defined as increased production per unit area of land (Donald et al., 2001). Since 1950, technological improvements have allowed intensification of European agricultural systems per hectare (ha) and per animal. Thus, according to the Food and Agricultural Organisation of the United Nations (FAOSTAT, 2015), from 1967 to 2013, average crop yields per ha increased, for example, by 323% for grain maize and 300% for soft wheat in the European Union. The same trend is observed in dairy production, where average European annual production per cow increased by 237%. Several phenomena contributed to the intensification of dairy production systems, whether considered per

Summary of abbreviations: AC, acidification; AHC, ascendant hierarchical clustering; C, carbon; CED, cumulative energy demand; CV, coefficient of variation; DM, dry matter; EcoSys, ecosystems; EcoTox, freshwater ecotoxicity; EU, eutrophication; FAMD, factorial analysis for mixed data; FPCM, fat and protein corrected milk; FU, functional unit; G, grass-based milk production TMR; GWP, global warming potential; Ha, hectare; H-AgrB, highland milk production system from AGRIBALYSE; IG, intensive grass-based milk production TMR; IM, intensive maize silage-based milk production TMR; kg, kilogramme; LC, land competition; LCA, life cycle assessment; LCI, life cycle inventory; LUC, land use change; LW, live weight; M, maize silage-based milk production TMR; MJ, megajoule; O, organic milk production TMR; TMR, technological management route; VIM, very intensive maize silage-based milk production TMR.

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animal or per ha. Intensification per cow was due mostly to a better feed conversion ratio, while intensification per ha was due to increased production per cow, lower culling and replacement rates of cows and increased forage and crop yields per ha (Crosson et al., 2011).

In Europe, the structure of the dairy sector has been strongly influenced by the Common Agricultural Policy of the European Union. Dairy quotas were set in 1984 to address a surplus of milk and low milk prices. Based on reference volumes for 1983, a quota was allocated to each Member State. The aim of this policy was to control milk production, to stabilise milk prices and the incomes of milk producers, and to reduce the budget for market support (Barthélemy and David, 1999; JRC and IPTS, 2009; Kroll et al., 2010). In France, dairy quotas were administratively managed to reach two objectives: maintain dairy production over the entire territory and encourage the development of medium-sized farms to facilitate the establishment of young farmers (Barthélemy and David, 1999; Lelyon et al., 2012; Pflimlin et al., 2009).

With this policy, however, the comparative advantages of French regions for milk production were not fully exploited. Dairy production was maintained in regions with lower comparative advantages and did not increase in regions with higher comparative advantages. However, the French dairy sector has evolved in the past decade. As production per cow increased, the number of dairy cows decreased (CNIEL, 2014). The recent end of dairy quotas is expected to enhance this phenomenon (Perrot et al., 2014) and induce a concentration of milk production in favourable areas, mostly in western France (Kroll et al., 2010; Perrot et al., 2014; Peyraud and Duhem, 2013). Reduced supply costs, positive externalities and agglomeration economies will drive the concentration of dairy farms (Chatellier et al., 2013). Thus, concentration and intensification of the dairy sector seem unavoidable, i.e. bigger farms, increased production per cow and per ha, with more maize silage and concentrate feed in the diet. In this context, it is important to know which dairy systems combine high productivity and low environmental impacts.

The concentration of livestock production is known to lead to negative impacts on soil, air and water (Chatellier et al., 2013; European Commission, 2013; Peyraud et al., 2012). Intensification of milk production, which we define as increased production per ha, invariably leads to increased impacts per ha, but its impacts per kg of milk are less clear (Crosson et al., 2011), and few studies have investigated this. In studies that exclude greenhouse gas emissions from land-use change (LUC), Bell et al. (2011) and Casey and Holden (2005) showed that increasing milk production per total ha (on- and off-farm) occupied may lead to reduced Global Warming Potential (GWP) per kg of milk under certain conditions. For example, improvements in feed efficiency, fertility and cow longevity were identified as important parameters to reach increased yield per dairy cow and lower GWP and land occupation per kg of milk (Audsley and Wilkinson, 2014; Yan et al., 2013).

Basset-Mens et al. (2009), Bava et al. (2014) and Battini et al. (2015) investigated a range of impacts of increased milk production per ha of on-farm land. When we calculated these impacts per total ha of land occupied, the systems compared by Basset-Mens et al. (2009) and Bava et al. (2014) produced similar amounts of milk. In the study by Battini et al. (2015), the systems that produced more milk per ha of on-farm land also produced more milk per total ha of land occupied. When milk production per ha of on-farm land increased, Basset-Mens et al. (2009) found increased GWP, acidification, eutrophication and energy use per kg of milk produced, but Bava et al. (2014) found no significant change in these impact categories or land competition per kg milk. Battini et al. (2015) found that increased milk production per ha of total land occupied reduced the impact on eutrophication, biodiversity, non-renewable energy use, land competition and – excluding LUC and C sequestration – GWP per kg of milk produced. Acidification and GWP – including LUC and C sequestration – per kg of milk were not affected by increased milk production per total ha occupied.

The few studies that investigated environmental impacts of dairy system intensification focused on a narrow range of diversity in systems. Casey and Holden (2005) assessed 10 farms in and out of an agri-environmental scheme; Basset-Mens et al. (2009) compared three dairy farming systems differing in N fertiliser use and maize silage supplementation; Bell et al. (2011) compared a high-forage summer-grazing system to a low-forage non-grazing system; and Bava et al. (2014) and Battini et al. (2015) compared 28 and four confinement farms, respectively, covering a wide range of milk production per ha of on-farm land.

The aim of this study was to use Life Cycle Assessment (LCA) to assess a range of environmental impacts of contrasting dairy systems that represent a wide diversity of management practices and intensification levels. We estimate impacts of dairy system intensification and identify the most promising production systems, considering both production level and environmental impacts. This information will be useful to inform agricultural policy in a post-quota context.

2. Materials and methods

2.1. Definitions

In this article, we distinguish intensification per animal, which is quantified by milk production per cow, from intensification per unit land area, which is quantified by milk production per ha of on-farm and off-farm land. We use total cumulative energy demand (CED) per ha as an additional indicator of dairy system intensification.

2.2. Identification of technical management routes

2.2.1. Construction of the database

We used the concept of the technical management route (TMR), i.e. a logical set of technical options designed by farmers (Renaud-Gentié et al., 2014), to describe the diversity of lowland milk production systems in France. To characterise TMRs, we used the following 12 indicators of technical options: concentrate feed intake (kg dry matter (DM)/cow/year), maize silage intake (kg DM/cow/year), grazed and conserved grass intake (kg DM/cow/year), maximum area accessible for grazing (ha), grazing (yes or no), grazing duration (days/year), cow breed, age at first calving (months), grouping of calving (yes or no), replacement rate (%), milking parlour technology and type of production (conventional or organic). We used detailed descriptions published by the *Institut de l'Elevage* and the *Chambres d'Agriculture* (IDELE, 2015) to construct a database containing the values of the 12 indicators for 172 French lowland dairy farms. The database was refined, and farms with more than two missing values for the selected indicators were removed, leaving 69 farms for analysis.

2.2.2. Statistical analyses

To identify the most representative TMRs, we adapted and simplified the method that Renaud-Gentié et al. (2014) developed to identify vineyard TMRs. The method combines Factorial Analysis for Mixed Data (FAMD) and Ascendant Hierarchical Clustering (AHC). Statistical analyses were performed with R software (R-Development-Core-Team, 2007). Missing data in the database were imputed with the "imputeFAMD" procedure (Audigier et al., 2016) from the "missMDA" package (Husson and Josse, 2014). Then, a FAMD was performed with the "FAMD" procedure (Pagès, 2004) from the "FactoMineR" package (Husson et al., 2014).