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Environmental footprint of the integrated France–Italy beef production system assessed through a multi-indicator approach

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ABSTRACT

This study aims to evaluate the environmental footprint of the integrated France–Italy beef production system (extensive grassland-based suckler cow-calf farms in France with intensive cereal-based fattening farms in northeastern Italy) using a multi-indicator approach, which combines environmental impact categories computed with a cradle-to-farm gate Life Cycle Assessment, and food-related indicators based on the conversion of gross energy and protein of feedstuffs into raw boneless beef. The system boundaries were set from the calves' birth to their sale to the slaughterhouse, including the herd management, on- and off-farm feed production and materials used on the farms. One kilogram of body weight (BW) sold was used as the functional unit. The study involved 73 Charolais batches (i.e., a group of animals homogenous for age, finishing period and fattening farm), kept at 14 Italian farms. Data from 40 farms originating from the Charolais Network database (INRA) were used to characterize the French farm types, which were matched to the fattening batches according to the results of a cluster analysis. The impact categories assessed were as follows (mean ± SD per kg BW): global warming potential (GWP, 13.0 ± 0.7 kg CO_2-eq, reduced to 9.9 ± 0.7 kg CO_2-eq when considering the carbon sequestration due to French suckler cow-calf system permanent grassland), acidification potential (AP, 193 ± 13 g SO_2-eq), eutrophication potential (EP, 57 ± 4 g PO_4-eq), cumulative energy demand (CED, 36 ± 5 MJ), and land occupation (LO, 18.7 ± 0.8 m^2/year). The on-farm impacts outweighed those of the off-farm activities, except in the case of CED. On average, 41 MJ and 16.7 kg of dietary feed gross energy and protein were required to provide 1 MJ or 1 kg of protein of raw boneless beef, respectively, but nearly 85% and 80%, respectively, were derived from feedstuffs not suitable for human consumption. Emission-related (GWP, AP, EP) and resource utilization categories (CED, LO) were positively correlated. Food-related indicators showed positive correlations with emission-related indicators when the overall feedstuffs of the diet were considered but negative correlations when only the potentially human-edible portions of the beef diets were considered. In conclusion, the integration of the pasture-based France suckler cow-calf system with the cereal-based Italian fattening farms allows for the exploitation of the resources available, increasing the share of non-human-edible feedstuffs while maintaining good livestock productive efficiency. Combining indicators of impact categories with indicators of feed net supply may improve the assessment of the environmental footprint of livestock systems.

1. Introduction

Several studies have recognized beef production systems as important contributors to agricultural emissions of climate-altering, acidifying and eutrophying compounds, as well as to the exploitation of natural resources (Steinfeld et al., 2006; de Vries and de Boer, 2010, Gerber et al., 2013). At the same time, beef production systems produce a variety of positive outputs, contribute to food security and to the recycling of nutrients contained in feeds non-edible by humans into high-protein food of valuable nutritional quality (Oltjen and Beckett, 1996; Schiere et al., 2002; FAO, 2007; Ertl et al., 2016).

Different methods have been developed to evaluate the sustainability of the livestock sector, ranging from farm characteristics predictors to effect-based indicators (Lebacq et al., 2013). Among these, Life Cycle Assessment (LCA; ISO, 2006; Finnveden et al., 2009) has emerged as one of the most suited methodologies for evaluating the

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environmental impact of livestock systems (De Vries and de Boer, 2010; Lebacq et al., 2013). However, the LCA methodology usually does not account for some essential benefits of the beef production systems, such as the contribution to food security and the diverting of non-human-edible foodstuffs to animal feeding (Gill et al., 2010; Wilkinson, 2011). Therefore, approaches based on the use of different indicators could improve the assessment of livestock systems, particularly when different agro-ecosystems are involved in the production cycle (Cucek et al., 2012; Röös et al., 2013). This is the case in the integrated France–Italy beef production system. This system is characterized by a geographical separation of the grassland-based suckler cow-calf phase, mainly located in the French Massif Central semi-mountainous area (Brouard et al., 2014), and the intensive, cereal-based fattening phase, located in northeastern Italy, where intensive beef fatteners import the young bulls and rear them using total mixed rations based on maize silage and concentrates (Gallo et al., 2014). Different surveys have described various aspects of the system (Xiccato et al., 2005; Sturaro et al., 2009; Brouard et al., 2014; Gallo et al., 2014), but a comprehensive assessment of its sustainability is still lacking.

The aim of this study was to evaluate the environmental footprint of the integrated France–Italy beef production system using a multi-indicator approach, which combines emission-related – global warming (GWP), acidification (AP) and eutrophication (EP) potentials – and resource utilization – cumulative energy demand (CED) and land occupation (LO) – impact categories computed using a cradle-to-farm gate LCA methodology with food-related indicators (gross energy and protein conversion ratio and competition with direct human use of potentially human-edible feedstuffs).

2. Materials and methods

2.1. Goal and scope definition

The parameters of the LCA model for assessing the environmental footprint of the integrated France–Italy beef production system were set as follows. A cradle-to-farm gate LCA model was considered, taking into account the fattening batch as reference unit. The batch is defined as a group of stock calves, homogeneous for genetic type, origin, finishing herd, fattening period, and characteristics of the diet. The time period of each batch consisted of the whole productive cycle, from the birth of the calves to the sale of beef bulls to the slaughterhouse. Therefore, the system boundaries included the French suckler cow-calf herd, the Italian fattening phase and the transport from France to Italy. The impacts due to the herd management, the production of on- and off-farm feedstuffs, the production and use of industrial (fuel, plastic, lubricant) and bedding materials and the transport of inputs and animals (Fig. 1) were taken into account for both the French suckler cow-calf and the Italian fattening phases. The impact categories assessed were GWP, AP, EP, CED and LO and their magnitude was reported to 1 kg of body weight (BW) sold, which was taken as the functional unit. Land occupation was partitioned according to the agronomic destination: land surface area maintained as grassland (LO grass), land surface area cultivated for producing feedstuffs directly used for feeding animals (LO cropland), and the share of land surface area economically allocated to the production of agricultural by-products used in the beef diets (LO by-products).

Being the suckler cow-calf phase a multi-functional system producing more than one product, such as weaned male and female calves and cull cows, the allocation problem was resolved applying a mass allocation method. As the results of the LCA approach could be influenced by the allocation method chosen (ISO, 2006), a sensitivity analysis was performed by also considering an allocation of the impacts based on a protein method (relative importance of the protein in BW sold) and an economic method (relative importance of the revenue obtained by the sale of animals). For details, see Supplementary Table 1.

2.2. Life cycle inventory and life cycle impact assessment

2.2.1. Data collection and editing for the northeastern Italy fattening sector

The starting Italian dataset included 137 Charolais young bull batches. As the usual calving period in the French suckler cow-calf system is concentrated between November and April (Brouard et al., 2014), for this study, only the Italian batches of young bulls born in these months were retained. This editing provided 73 batches involving 4882 animals herded in 14 intensive beef fattening farms in northeastern Italy. For each farm, the land surface area used for the production of feedstuffs and the spreading of manure, the herd size, the use of chemical fertilizers and concentrates, and the amount of bedding materials, fuel and electricity consumed were collected by a unique operator through farm visits. The allocation of the different inputs to each batch within the farm was based on the utilization of each on-farm feed into the diet (agricultural inputs) and on the average amount of input per animal and per day (bedding and industrial inputs). Information collected for each batch included the number of animals, the purchase and sale dates and BW at the purchase in France (BWS), at the arrival to the Italian fattening farm (BWI) and at the end of the finishing period (BWF). The average daily gain (ADG, kg/day) was calculated as the difference between BWF and BWI divided by the total animal presence (animals × days).

Diet formulation and feed allowance, assumed equal to feed intake, were collected monthly for each diet used within each farm. All diets were sampled at the manger for the chemical composition analysis. Crude protein, ether extracts, crude fiber, ash, starch, neutral detergent fiber and non-starch carbohydrate content were assessed using the near-infrared spectroscopy method, whereas phosphorus (P) content was assessed according to the AOAC (2003) procedure (AOAC 999.10, 2000 and ICP-OES). Total monthly feed intake was calculated for each batch as the mean of two subsequent recorded daily feed intakes multiplied by the number of days between the two recordings. The feed intake in the period following the arrival of the batch at the farm was assumed equal to that of the first record, and that in the period preceding the sale of the batch to the slaughterhouse was assumed equal to the last recorded. The total feed intake for each batch (kg DM) was calculated as the sum of the monthly feed intakes and referred to the entire fattening period (sale date–arrival date), and the daily dry matter intake (DMI, kg DM/animal/day) was computed as the total feed intake divided by the length of the fattening period. The share of the maize silage in the DMI and the share of the dry matter ration produced on-farm (self-sufficiency rate) were also computed for each batch. Descriptive statistics of the Italian beef fattening farms and of the main traits of beef batches are given in Table 1, whereas the composition and characteristics of fattening diets are shown in Supplementary Tables 2 and 3, respectively, and the agricultural inputs for on-farm feedstuffs production are given in Supplementary Table 4.

The gross and digestible energy contents of the diets were calculated according to INRA (2007). The nitrogen (N) input-output flow was calculated for each batch according to the guidelines for the calculation of manure N production to be used within the framework of the European Union (EU) Nitrates Directive (Ketelaars and Van der Meer, 1999). The N intake was computed as the average daily DMI × finishing duration × average N content of the diet; the N retention was ((BWF − BWI) × 0.027 kg N/kg BW); and the N excretion was the difference between N intake and N retention. The excretion of P was calculated using the same procedure, with the average P dietary content and a retention factor of 0.0075 kg P/kg BW (Whiters et al., 2001).

2.2.2. Connection of the French beef suckler cow-calf and Italian beef fattening databases

The French data originated from the Charolais Network database of the INRA (Liénard et al., 1998) and concerned 40 suckler cow-calf farms surveyed annually. As stock calves from French beef suckler herds are usually collected by brokers who set up batches to be sold to Italian