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Research article

The effect of lameness on the environmental performance of milk production by rotational grazing

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ABSTRACT

Dairy production leads to significant environmental impacts and increased production will only be feasible if the environmental performance at farm level permits a sustainable milk supply. Lameness is believed to become more prevalent and severe as herd sizes increase, and can significantly reduce milk output per cow while not influencing other attributes of the production system. The objective of this work was to quantify the effect of lameness on the environmental performance of a typical grazed grass dairy farm and evaluate the theoretical value of sensor-based real-time lameness management. Life cycle assessment was used to compare a typical baseline farm with scenarios assuming increased lameness severity and prevalence. It was found that lameness could increase the farm level global warming potential, acidification potential, eutrophication potential and fossil fuel depletion by 7–9%. As increased herd sizes will increase cow: handler ratio, this result was interpreted to suggest that the use of sensors and information and communication technology for lameness detection could improve management on dairy farms to reduce the adverse impact on environmental performance that is associated with lameness.

1. Introduction

Globally, livestock production is believed to have adverse environmental consequences, impacting air, water, soil and ecology (IDF, 2009). Ireland is an example of a country that generates significant GDP (gross domestic product) (1.5%) from cattle (Teagasc, 2012), at the cost of agriculture being the single largest contributor (>20%) to greenhouse gas (GHG) emissions (Duffy et al., 2014; Hynes et al., 2009). With the abolishment of the EU milk quota (Kempen et al., 2011), the output of the Irish dairy industry is expected to increase by 50% by 2020 (Department of agriculture, 2010). The Irish Environmental Protection Agency (EPA) estimated that the GHG emissions from the Irish dairy sector will increase by 12% as a consequence (EPA, 2012). Similar trends may apply in other countries and regions because of the increasing global demand for dairy products (Mekonnen and Hoekstra, 2012). Reducing the environmental impact of dairy farms striving for increased productivity is a significant issue for all stakeholders in the dairy supply chain (Hristov et al., 2013).

There have been many studies of the environmental impact of milk production (Fantin et al., 2012; Thomassen et al., 2008; Yan et al., 2013a), with a tendency to focus on GHG emissions (Casey and Holden, 2005; Dalgaard et al., 2014). Life cycle assessment (LCA) has been widely used for such assessments (O'Brien et al., 2012; Thomassen et al., 2008; Yan et al., 2013b), and (Meul et al., 2014) demonstrated that LCA can support environmental decision making at the commercial dairy farm level. These LCA models can help farmers to identify environmental hotspots to focus improved management and (Yan et al., 2013b) showed that LCA could be used to evaluate the contribution of specific management tactics on the impact of milk production.

Lameness in dairy cattle refers to any abnormality which causes an altered gait, and is a major health and welfare issue for dairy farms (Cha et al., 2010). It is generally believed to influence the milk yield of affected cows and is related to a number of key management tactics (Barnes et al., 2011; Gomez and Cook, 2010). Some authors (Tranter and Morris, 1991; Warnick et al., 2001; Whitaker et al., 1983) found lameness decreased milk yield until treated (Lucey et al., 1986), found a decrease that continued after treatment and (Cobo-Abreu et al., 1979) observed no change in yield. Recent studies have found that lameness causes reductions in milk yield and profit at the farm level (Borderas et al., 2008; Bruijnis et al.,

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2010; Ettema and Østergaard, 2006), while (Green et al., 2002) found that over 70% of cows became lame at least once in a year with a total mean reduction in milk yield per 305-day lactation of approximately 360 kg. The decrease in milk yield from lame cows is mainly because of a reduction in standing time for feeding and a lack of willingness to move for feeding and milking (Bach et al., 2007; Miguel-Pacheco et al., 2014). This can reduce feed use efficiency (Bareille et al., 2003; Palmer et al., 2012) potentially exacerbating the environmental impacts associated with milk production process. There is scope to develop information driven operational management specific to lameness that could allow farm managers to improve the feed usage efficiency and optimise treatment to reduce the environmental impacts at the farm level. While the economic cost of lameness management is reasonably well understood (Bruijnis et al., 2010; Cha et al., 2010), baseline environmental impacts of lameness are not known.

The objective of this work was to quantify the effect of lameness on the environmental performance of a typical grazed grass dairy farm and evaluate the theoretical value of sensor-based real-time lameness management. LCA was used to model a typical Irish low-cost, grass-based, rotational grazing dairy farm (Fitzgerald et al., 2005), which was then compared with scenarios combining ranges of prevalence and severity of lameness in the herd.

2. Materials and methods

LCA was used to evaluate the environmental impact using four stages: (1) goal and scope, (2) life cycle inventory analysis, (3) life cycle impact assessment and (4) interpretation (ISO, 2006a, 2006b) using Gabi 6.0 (PE-International, 2012).

The goal of the study was to evaluate the impact of lameness on the environmental performance of milk production. This was undertaken to establish a baseline for evaluating the value of sensor and ICT derived information for real-time lameness management.

The system was low-cost (use less purchased feed than confinement system), grass-based rotational gazing milk production (Fitzgerald et al., 2005) operating over one year. The system boundary was from cradle to farm gate, including land preparation, cultivation process and nutrient management for grass production, production and transportation of synthetic fertilizers, silage and concentrated feed, production and use of electricity and diesel on farm (Fig. 1). Infrastructure (expect the manure storage tank), farm and milking machinery, refrigerant for milk cooling, pesticides, udder disinfectants and disposal of silage plastic was not included due to data unavailability, but these were not thought to be influenced by the lameness scenarios. All manure was assumed to be spread on the grazing and grass silage areas of the farm. GHG associated with manure spreading and CO_2 from farming machinery were included. Soil carbon sequestration was not included because the model farm was assumed to be mature and in equilibrium (IPCC, 2006). The functional unit was “1 kg of energy corrected milk (ECM) delivered at the farm gate” (Sjaunja et al., 1990) with ECM calculated as below:

$$\text{ECM} = \text{milk delivered} \times (0.25 + 0.122 \times \text{fat\%} + 0.077 \times \text{protein\%} \qquad (1)$$

In order to differentiate the dairy from non-dairy activities (e.g. producing heifers for sale) allocation was by the method of Yan et al. (2013b). All animal numbers were expressed as livestock unit (LU) equivalents based on the ratio of nitrogen excretion compared with a typical dairy cow with the allocation factor as the proportion of all dairy LU to total LU. The allocation between milk and co-product meat from dairy cows was based on the energy and protein requirement of herd (O'Brien et al., 2012). The proportion of the total energy and protein requirements of the herd for meat production in an Irish pasture based system was taken as 12% (Shalloo et al., 2004).

The activity data (Table 1) were taken from Yan et al. (2013b), who reported data from a farm survey that represented a typical Irish commercial farm focused on milk production. Specific data for feed ingredients and their proportion were taken from (O'Brien et al., 2012) (Table 2), with background data taken from the ‘Thinkstep™ Food and Feed database’ (Thinkstep, 2014). The environmental impacts of concentrate feed co-products was allocated by economic methods based on relative market value using factors in the same database. As most of the concentrate feed used in Irish dairy farms is imported from the EU, the origins of crop production were assumed to be EU in proportion to market share.

The methods and emission factors (EF) used are shown in (Table 3). Methane (CH_4) emissions from enteric fermentation were dependent on feed intake and calculated following IPCC Tier 2 methods (IPCC, 2006). The net energy (NE) from pasture is estimated as the difference between total NE requirement (NE_L, NE_M and NE_P) and gross NE provided by silage and concentrate feed. The estimated milk output for NE_L included the milk consumed (301 kg/cow) by the calf and 6.5% of gross energy intake lost as CH_4 was taken as the emission factor because grazed grass was assumed to be the major dietary component for the dairy cow (O'Mara, 2006). CH_4 emissions from stored manure were estimated using national average EF (Duffy et al., 2014) following IPCC Tier 2 methods (IPCC, 2006). The CH_4 emission from manure deposited by animals on pasture was not included because the quantity is negligible (IPCC, 2006). The seasonal CH_4 emission factors used for manure application were the average of 12 g CH_4/m^3 for spring, 0.07 g CH_4/m^3 for summer and 6.8 g CH_4/m^3 for autumn (Chadwick et al., 2000) (Table 3) because specific time of manure application was not known.

Nitrogen emissions were mainly generated from animal excreta, with data taken from national inventory reporting (Duffy et al., 2014). Accordingly 36.2% of N in stored manure was assumed to contribute to indirect N_2O emission as NH_3, and the EF for liquid manure and solid manure was 0.01. Other N in stored manure was assumed to contribute to direct N_2O emission and the EF for liquid and solid manure was 0.01and 0.02, respectively. Manure on pasture accounts for indirect N_2O emission as NH_3 (5.6%) and NO_3 (10%), with EFs of 0.01 and 0.025, respectively. The remaining manure was assumed to contribute to direct N_2O emission and EF was 0.02. According to previous ammonia report on Irish grass land (Hyde et al., 2003), 1.6% of inorganic N fertilizers spread on field was volatilized as NH_3. The indirect N_2O emissions as NH_3 from manure and soiled water spreading were also included Table 3.

In order to calculate the potential leaching of N and P, a farm gate balance approach was used assuming an average P surplus taken from Buckley et al. (2013). The P surplus for specialist dairy farms in Ireland is between 1 and 10 kg, the P surplus lost to waterways was estimated using 0.5 kg P/ha per year (Schulte et al., 2011). According to IPCC (IPCC, 2006), 30% of the N from fertilizer, manure storage and excretion is lost through leaching in the form of nitrate (NO_3).

Greenhouse Gas emissions related to on-farm energy consumption (diesel consumption for field activities and electricity use for heating, milking and cooling processes) were estimated from the amount of diesel (litres) and electricity (kWh) used and EFs from Eco-invent 3.0 (Ecoinvent, 2014) and specific LCIA methods as deployed in Gabi 6.0. Fertilizer was assumed to be produced outside Ireland, primarily from Germany (lime, nitric acid, phosphate fertilizer) with some production data (Potassium Chloride) from the EU-27. The compound fertilizer (N—P—K) was assumed to be mixed from calcium ammonium, nitrate, urea, diammonium phosphate,