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The carbon footprint of pasture-based milk production: Can white clover make a difference?

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ABSTRACT

Carbon footprint (CF) calculated by life cycle assessment (LCA) was used to compare greenhouse gas emissions from pasture-based milk production relying mainly on (1) fertilizer N (FN), or (2) white clover (WC). Data were sourced from studies conducted at Solohead Research Farm in Ireland between 2001 and 2006. Ten FN pastures stocked between 2.0 and 2.5 livestock units (LU)/ha with fertilizer N input between 180 and 353 kg/ha were compared with 6 WC pastures stocked between 1.75 and 2.2 LU/ha with fertilizer N input between 80 and 99 kg/ha. The WC-based system had 11 to 23% lower CF compared with FN (average CF was 0.86 to 0.87 and 0.97 to 1.13 kg of CO_2-eq/kg of energy-corrected milk, respectively, 91% economic allocation). Emissions of both N_2O and CO_2 were lower in WC, whereas emissions of CH_4 (per kg of energy-corrected milk) were similar in both systems. Ratio sensitivity analysis indicated that the difference was not caused by error due to modeling assumptions. Replacing fertilizer N by biological nitrogen fixation could lower the CF of pasture-based milk production.
Key words: carbon footprint, life cycle assessment, white clover, milk production

INTRODUCTION

Because of projected population growth and demand for dairy products (Steinfeld et al., 2006), urgent action is needed to achieve a sustainable balance between profitability and the environmental impact of dairy production. The global dairy sector was estimated to contribute 4% of anthropogenic greenhouse gas (**GHG**) emissions in 2007 (Gerber et al., 2010). In countries with small human populations and large cattle populations such as Ireland, agriculture is the largest contributor (30.5% in Ireland) to GHG emissions (Ireland EPA, 2012). As milk production accounts for over one-third of the output of Irish agricultural commodities (Anonymous, 2011), GHG emissions from milk are important to policy makers. Tools are needed to assist with strategic policy development to enable the dairy sector to thrive while minimizing GHG emissions.

Life cycle assessment (**LCA**; ISO, 2006) has been developed to assess the environmental impact through the life cycle of products, from the "cradle" (production of raw materials such as iron ore) to the "grave" (the waste management of products after consumption). When applied to agricultural products, attention is often focused on "cradle to farm gate" because the greatest impact is found in the production stage (Schau and Fet, 2007). Because of global concerns about GHG emissions from livestock production, the LCA interpretation of GHG emissions is performed more often than other impact categories (e.g., eutrophication) and is referred to as carbon footprint (**CF**; O'Brien et al., 2010; Rotz et al., 2010; Flysjö et al., 2011). The main GHG from agriculture are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). For pasture-based milk production, mineral fertilizer and recycled organic manures are the main N inputs to grassland and the main sources of N_2O emissions from farms. Typical management in grazing systems uses mineral fertilizer N (**FN**) as the predominant source of N for grassland (referred to hereafter as FN management) in addition to manure.

In temperate pastures, biological N fixation (**BNF**) from forage legumes can also be a significant source of N (10 to 300 kg of N/ha per year; Ledgard et al., 2009). Because of increasing fertilizer prices and stringent regulation of N use on farms (European Council, 1991), white clover (*Trifolium repens* L.) is becoming an increasingly profitable alternative to FN for pasture-based dairy production (Humphreys et al., 2012). Management of white clover (**WC**) in grassland (hereafter referred to as WC management) provides BNF, which displaces the need for fertilizer N and the GHG emissions associated with fertilizer N in the system. Measurement under field conditions at Solohead Research Farm (Co. Tipperary, Ireland) showed that use of WC reduced N_2O emissions by 19% (Li et al., 2011). Stud-

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Table 1. Characteristics of the milk production based on fertilizer N (FN)- and white clover (WC)-based systems at Solohead Research Farm (Co. Tipperary, Ireland) between 2001 and 2006 (Humphreys et al., 2008, 2009)[1]

	2001–2002[2]					
	WC	FN			2003–2006	
Characteristic	N205	N230	N300	N400	WC	FN
Stocking rate,[3] LU/ha	1.75	2.1	2.5	2.5	2.0; 2.2	2.0; 2.2
Synthetic fertilizer N, kg/ha	80	180	248	353	90	226
Concentrate feed, kg/cow per year	536	536	536	536	520	531
Milk delivered at farm gate, kg/cow	6,550	6,275	6,242	6,375	6,521	6,526
Milk fat, %	4.1	4.2	4.1	4.2	4.2	4.2
Milk protein, %	3.5	3.6	3.5	3.6	3.5	3.6
Biological-N fixation, kg/ha per year	87.4	9.1	3.2	0.1	112.5	12.2

[1]Data are means of 2 and 4 yr, respectively.

[2]The acronyms for 2001 and 2002 are consistent with Humphreys et al. (2008); no acronyms were previously defined for the experiments between 2003 and 2006.

[3]The stocking rate (LU = livestock unit) was 2 for 2003 and 2.2 for 2004 to 2006.

ies using model estimates in the Netherlands (Schils et al., 2005) and New Zealand (Basset-Mens et al., 2009) indicated that milk produced from WC has a CF between 10 and 15% lower than that from FN. Following from the study of Li et al. (2011), which was concerned solely with emissions of N_2O from WC and FN, the objective of the current study was to use LCA to conduct a holistic comparison of WC and FN using data from experimental systems at Solohead Research Farm to determine the difference in GHG emissions, including CO_2 and CH_4. Specific objectives were to (1) compare the CF of pasture-based milk production from FN and WC, (2) compare the modeled and measured N_2O emissions at the same site under similar management conditions, and (3) evaluate the sensitivity of the CF model.

MATERIALS AND METHODS

The 4 stages of LCA methodology: goal and scope definition, life cycle inventory, life cycle impact assessment, and result interpretation (ISO, 2006), were implemented as follows.

Goal and Scope

In the goal and scope phase, the production system is described, a functional unit (**FU**, to which all subsequent inputs and outputs are related) and system boundary (which determines the processes associated with the delivery of the FU) are defined, and in case of multiproduct systems, the allocation procedure between products is specified (ISO, 2006). The goal of the current study was to assess the role of CF for comparing milk production using FN and WC management in low-cost, grass-based, rotational grazing systems. Management data were obtained from experimental systems at Teagasc Solohead Research Farm (52°51′ N, 08°21′ W) between 2001 and 2006 (Table 1; Humphreys et al., 2008, 2009). The first experiment had 4 systems (1 WC and 3 FN) in 2001 and was replicated in 2002. The second experiment had 2 systems (1 WC and 1 FN) in 2003 and was replicated in 2004, 2005, and 2006, resulting in 16 data sets being analyzed for this study. The LCA model was developed in Simapro (PRé Consultants, 2011) and was replicated for each system separately. The FU was defined as 1 kg of ECM at the farm gate (Sjaunja et al., 1990):

$$\text{kg of ECM} = \text{kg of milk} \times (0.25 + 0.122 \times \text{Fat \%} + 0.077 \times \text{Protein \%}), \quad [1]$$

where kg of milk is the total milk delivered from the herd in 1 yr. To account for on-farm consumption by calves, 301 kg of milk per cow was subtracted from the milk yield each year (O'Mara, 2006).

The system boundary was cradle-to-farm gate, including the foreground processes of milk production on the farm and the background processes of production and transportation of mineral fertilizer; cultivation, processing, and transportation of concentrate feed (except citrus pulp and minerals due to lack of data); production and use of electricity and diesel fuels; and clover seed. Infrastructure (sheds, slurry lagoon, roads), machinery (tractor, milk cooling system), medicines, pesticides, and disposal of plastic for baled silage were not included due to lack of relevance for comparison or because they were shared by both FN and WC management. Bulls were not accounted for because cows were inseminated by AI. Soil carbon sequestration was not