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Effect of cattle genotype and feeding regime on greenhouse gas emissions intensity in high producing dairy cows

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ABSTRACT

Improving milk production through livestock feeding and genetics is a promising approach for reducing greenhouse gas emissions (GHG) from dairy production systems. This study investigated emissions intensity, defined as the global warming potential (GWP) per unit energy corrected milk (ECM) output, of high-producing dairy systems. Objectives of this study were: to determine the effect of forage regime and cattle genetic line on GHG emissions from the life cycle of four directly comparable dairy production systems; to examine differences amongst contributing GHG emissions sources, and to identify key parameters contributing the most uncertainty in overall GWP. Life cycle analysis (LCA) was conducted based on seven years data collected from a long-term Holstein-Friesian genetic and management systems project. The four dairy production systems comprised two feeding regimes of High and Low Forage applied to each of two genetic lines. The Control line represented the average UK genetics and Select line representing the top 5% of UK genetics for milk fat and protein.

Select genetic line animals managed under Low Forage regime was estimated to hold potential to reduce emissions intensity by 24% compared to Control genetic merit cows managed under a High Forage regime. Individually, improving genetic merit of the herd and implementing Low Forage regime hold potential to reduce emissions intensity by 9% and 16%, respectively. Key factors in the differences amongst systems were greater off-farm emissions under Low Forage regime, and greater on-farm nitrous oxide emissions associated with High Forage. In contrast to overall emissions, the emissions intensity was lower in Low Forage groups than in High Forage groups because of high milk yield in Low Forage groups. Six key parameters contained the greatest influence on uncertainty in results. These included: three Intergovernmental Panel on Climate Change (IPCC) coefficients concerning indirect emissions from volatilized nitrogen (EF_4), direct nitrous oxide emissions from nitrogen input to soil (EF_1), and emissions from direct deposition of excreta at pasture (EF_{3PRP}); and three system-specific emissions factors for animals' excreted nitrogen rate, enteric methane and manure methane. The coefficients EF_4, EF_1, and EF_{3PRP} should be prioritized for better definition in order to minimize uncertainty in future studies.

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1. Introduction

1.1. Background

There has been increasing attention paid during the past decade to the contribution of food production to climate change and the challenge faced by society's current demand for products such as meat and dairy. Globally, the dairy sector contributes 4% of the total anthropocentric greenhouse gas (GHG) emissions (FAO, 2010). If the dairy industry is to meet the growing global demand for dairy products, ways to minimize GHG emissions per unit product will become increasingly important. Gerber et al. (2011) defined the GHG emissions per unit physical output as the emissions intensity of dairy production. Many countries have established ambitious GHG reduction targets, and the UK dairy industry has identified a target of 20–30% reduction by 2020 (Dairy Roadmap, 2013) compared to 1990 levels. The magnitude of emissions means that any potential improvements made in the global warming potential (GWP) of dairy production systems will make a substantial contribution towards attaining climate change targets around the world.

1.2. Greenhouse gas emissions from dairy production systems

Component GHG contributing to the total GWP of dairy production systems arise from processes both on and off the farm. Methane (CH_4) arises from enteric fermentation in ruminant animals, and from an aerobic fermentation of stored animal manures. Enteric CH_4 is influenced by the animal's feed intake, feed composition and the type of feed consumed (Chagunda et al., 2009; Garnsworthy et al., 2012). Emissions of nitrous oxide (N_2O) arise both directly and indirectly from multiple on farm sources (de Boer, 2003). These include the deposition of manure and urine on pasture, application of manure and chemical fertilizers to crops, and from decomposition of crop residues in the soil (IPCC, 2007). Carbon dioxide (CO_2) emissions derive mainly from energy use on the farm and in the processes surrounding external production and transport of purchased feeds and fertilizers. The dynamic relationship between the operational and natural processes of a dairy production system leads these three GHG to be inexorably linked. Thus even a small shift in the balance of these GHG emissions produced may lead to a substantial difference in overall GWP.

Steinfeld et al. (2006) stated that the most promising approach for reducing emissions from livestock systems is by improving the efficiency of livestock production through feeding and genetics. It has been shown that high yielding dairy cows with high feed intakes are associated with a lower enteric CH_4 output per unit milk (Garnsworthy, 2004; Casey and Holden, 2005; Bell et al., 2010). However, Chagunda et al. (2009) showed that although increasing milk yield was associated with a reduction in enteric CH_4 per unit milk, there could be an increase in excreted waste nitrogen per unit milk and per hectare of land used depending on the genetic merit of animals and the specifics of the production system. It has also been demonstrated that while implementing an organic system can reduce overall emissions of CO_2 and N_2O, the reduction in GWP may be nullified by lower production and an inherent overall increase in enteric CH_4 (de Boer, 2003). Weiske et al. (2006) also noted that, due to the trade-offs amongst dairy GHG emissions, many mitigation measures suggested in the literature do not always result in the expected reduction potential when evaluated at the farm level. The overall GHG pollution potential from dairy production systems is therefore a dynamic process which should be assessed at a whole systems level in order to optimize the balance of the total output of pollutants against milk production. This whole system analysis can be performed using a method such as Life Cycle Assessment (LCA).

Over the past decade, studies have been undertaken at system level examining the relationships between GHG in dairy farms. Many studies have been aimed towards demonstrating the application of the LCA method in dairy farming (van der Werf et al., 2009; O'Brien et al., 2011). Furthermore, LCA studies assessing a whole farm system have been conducted mainly in the context of providing a comparison between the environmental efficiency of conventional and organic systems (de Boer, 2003; Thomassen et al., 2008), or between typical systems at a national level (Cederberg and Flysjo 2004; Saunders and Barber, 2007). A recent study by Kristensen et al. (2011) observed the large variations in GHG emissions per kg product that existed amongst farms within and not between conventional and organic production systems. Studies at production system level have not examined in depth the potential that exists to reduce emissions intensity within a herd through maintaining cows of different genetic merit under different feeding and management regimes.

1.3. Objectives

Objectives of this research were: (1) to determine the effect of forage regime and cattle genetic line on GHG emissions from the life cycle of four directly comparable dairy production systems; (2) to examine differences amongst contributing GHG emissions sources, and; (3) to identify key parameters contributing the most uncertainty in overall GWP.

2. Materials and methods

2.1. Dairy production systems

The study was based on Scotland's Rural College's (SRUC) established long-term Holstein-Friesian genetic and management systems project, situated at SRUC Dairy Research Centre, Crichton Royal Farm (CRF), Dumfries. Data used were collected over seven years, from January 2004 to December 2010, and incorporated specifics of four distinct dairy production systems within a conventional farm. Animals were maintained in two feeding regimes; High Forage (HF) and Low Forage (LF). The HF regime aimed to provide 75% by dry matter (DM) of the herd's total mixed ration (TMR) diet when indoors from home grown forage crops (ryegrass silage, whole-crop maize,