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Estimating greenhouse gas emissions from New Zealand dairy systems using a mechanistic whole farm model and inventory methodology

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ABSTRACT

The strategy for New Zealand dairy farming (DairyNZ, 2009) formulates targets for increased national milk production and a reduction in greenhouse gas (GHG) emissions, but acknowledges these two targets conflict because GHG typically increase with increased milk output. Our objective was to determine if both targets could be achieved by implementing combinations of five mitigations. A farm scale computer model, which includes a mechanistic cow model, was used to model a typical pasture based New Zealand dairy farm as the baseline farm. The five mitigations were: (1) improved reproductive performance of the herd resulting in lower replacement rates, (2) increased genetic merit of the cows combined with lower stocking rate and longer lactations, (3) keeping lactating cows on a loafing pad for 12 h/day for 2 mo during autumn, (4) growing low protein crops of grains and/or silages of maize, barley and oats on a portion of the farm and feeding this to lactating cows, (5) reducing fertilizer N use and replacing some of this with nitrification inhibitors and the plant growth stimulant gibberellins. No single mitigation strategy achieved both targets of increasing production by 10–15% and reducing GHG emissions by 20%, but when all were simultaneously implemented in the baseline farm, milk production increased by 15–20% to 1200 kg milk fat + protein/ha, and absolute GHG emissions decreased by 15–20% to 0.8 kg CO_2-equivalents (CO_2-e)/kg fat and protein corrected milk (FPCM), which is equivalent to a decrease from 11.7 to 8.2 kg CO_2-e/kg fat + protein. The synergies of the mitigations resulted in reduced dry matter intake and enteric CH_4 emissions, a reduction in N input and N dilution in feed, and, therefore, reduced urinary N excretion onto pastures, and an increase in feed conversion efficiency (*i.e.*, more feed was used for production and less for maintenance). Mechanistic CH_4 models as part of farm scale models are important because current GHG inventory methodology cannot properly evaluate CH_4 emissions for a range of potential mitigation strategies. There is also a need to develop capabilities in farm scale models to accurately simulate urine patches and N_2O emissions from these patches.

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Abbreviations: BCS, body condition score; CO_2-e, carbon dioxide-equivalents; DCD, dicyandiamide; DM, dry matter; FPCM, fat and protein corrected milk; GHG, greenhouse gas; IPCC, intergovernmental panel for climate change; ME, metabolizable energy; VFA, volatile fatty acids; WFM, whole farm model.

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1. Introduction

In New Zealand, CH_4 contributes 35% and N_2O 17% of annual greenhouse gas (GHG) emissions as CO_2-equivalents (CO_2-e). Agriculture contributes 48% of New Zealand's GHG emissions, most of it from pasture based livestock production systems. In these systems, enteric fermentation and urinary N are the most important sources of CH_4 and N_2O (Pinares-Patiño et al., 2009). Dairy farming in New Zealand is responsible for about 36% of agricultural GHG emissions (Ministry for the Environment, 2008), and 25% of the national exports in the year ending June 2008 (DairyNZ, 2009). Seasonal calving dairy cows are fed ryegrass dominant pastures. Typically, cows calve at the end of winter (*i.e.*, July–September) and are milked for 8–10 mo, which means that feed requirements are largely met from pasture. Supplements are typically up to 100 g/kg of feed intake, sometimes from outside the farm, and overseas, or grown on farm. Grains are rarely fed but silages are important feeds.

There is concern that dairy industry GHG emissions will increase with the potential for large financial penalties if a C tax is imposed. According to The Strategy for New Zealand Dairy Farming 2009/2020 (DairyNZ, 2009), two industry targets are to develop farm systems that increase milk fat and protein production per hectare, and reduce GHG emissions. In a previous modeling study, Beukes et al. (2010a,b) reported on implementation of GHG mitigation strategies on an average New Zealand farm, with the proviso that average milk production (~1050 kg fat + protein/ha) and profitability were not to be compromised, and showed that if production was to be maintained, and all potential gains from improved production efficiencies were to be channeled into reducing GHG emissions, mitigation of 27–32% of absolute emissions/hectare can be achieved with a potential increase in profitability.

Previous studies have summarized current and future strategies available to farmers to reduce GHG emissions by animal, feed based, soil and management interventions (Beauchemin et al., 2008; de Klein and Eckard, 2008). Only some of these strategies are feasible in pasture based systems, and there is a need to evaluate impacts of strategies when they are incorporated into farm systems, and cumulative effects when strategies are combined. Modeling is a tool to do this cost effectively, while comparing predictions from mechanistic CH_4 and N_2O models with emissions calculated using Intergovernmental Panel for Climate Change (IPCC) emissions factors (*e.g.*, when using inventory tools such as Overseer® (Wheeler et al., 2003)). It would be a step forward if modeling, using more accurate and detailed mechanistic models as research tools could evaluate potential mitigation strategies, and results used to inform widely used inventory methodology, such as decision support and policy analysis tools (Tamminga et al., 2007).

Our objective was to use a whole farm model (WFM) which mechanistically predicts enteric CH_4 from individual cows on a daily basis in order to evaluate impacts of some currently available mitigations on GHG emissions and milk production, and to compare results with those predicted by an empirical model (Overseer®) which uses inventory methodology. A complementary objective was to create a balance of increased milk production and reduced GHG emissions.

2. Methods

2.1. Approach

Information from DairyBase (www.dairybase.co.nz; a database used for benchmarking purposes by storing physical and financial data for individual New Zealand dairy farms) was used to describe a pasture based self-contained (*i.e.*, <100 g/kg bought in feed), typical dairy farm in the Waikato region of New Zealand. This baseline farm did not implement specific strategies to reduce GHG emissions. Selected mitigation strategies were incorporated individually into the baseline farm, but in combination and with different variations of each strategy. The following strategies were included.

2.1.1. Reproductive performance

Improved reproductive performance of the herd results in less involuntary culling and lower replacement rates. Replacement and other non-milk producing animals produce CH_4 and urinary N without contributing to milk production (Waghorn, 2008).

2.1.2. Feed conversion efficiency

Feed conversion efficiency is increased by using fewer animals with higher genetic merit that are milked longer. This strategy is based on dilution of maintenance energy requirements, where fewer efficient animals are required to produce the same milk fat + protein/unit land area. Thus CH_4 emitted and urinary N deposited/unit product is lower (de Klein and Eckard, 2008).

2.1.3. Standing cows on loafing pads (standing off)

'Standing off' is used to prevent a proportion of excreta from being deposited onto pastures during critical times of the year, such as late summer and autumn, and targets N_2O emissions. Late summer and autumn is the time when N uptake by pastures is slower and urinary N pools in the soil prior to the first winter rains which flush it below the root zone in the form of nitrate leaching, and/or making the N ready to be lost as N_2O when anaerobic soil conditions occur. Captured excreta from