Agricultural Systems 137 (2015) 1–11

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Optimizing ration formulation as a strategy for greenhouse gas mitigation in intensive dairy production systems

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ARTICLE INFO

Article history:
Received 23 October 2014
Received in revised form 18 March 2015
Accepted 24 March 2015
Available online 11 April 2015

Keywords:
Cost-effectiveness
Greenhouse gas mitigation
Dairy production

ABSTRACT

The study determines the extent to which ration selection can reduce GHG emissions in intensive dairy production systems. Replacing corn silage with alfalfa hay as the primary roughage component of dairy rations can lead to significant declines in GHG emissions from milk production in Ontario. Due to the higher soil organic matter of perennial forages, this change leads to the capture and storage of C in farm soils. Furthermore, alfalfa production requires less farm fieldwork and chemical inputs than corn which leads to a decline in emissions from energy consumption. The results suggest that feeding decisions have important implications for GHG emissions from intensive dairy production due to the wide variation in emissions for alternative crops that can be used in the ration. This is a notable finding, as much of the work on cost effective GHG mitigation in the dairy sector focuses on how this decision impacts enteric CH4. While our model estimates a decline in enteric CH4 resulting from the change in rations, this decline makes up only a small fraction of the total emission reductions. The ration decisions that lead to initial reductions in GHGs involve a small reduction in net farm returns but reductions beyond 5% impose a marginal abatement cost of about $550 Mg-1 CO2eq. Thus, reducing emissions by this amount through a carbon tax or market would not occur under current C prices suggesting that while intensive dairy production systems could contribute to policy efforts to reduce GHG emissions largely through cropping decisions, there may be more cost effective mitigation potential in other sectors.

1. Introduction

Growing evidence of the link between greenhouse gas (GHG) emissions and climate change is leading to efforts to determine cost effective strategies for mitigating GHGs. Globally, GHG emissions related to agricultural production are estimated at 15–25% of total anthropogenic GHGs (Tubiello et al., 2015; Vermeulen et al., 2012). Furthermore, global emissions of the two primary agricultural GHGs, methane (CH_4) and nitrous oxide (N_2O), are expected to rise by 35–60% by the year 2030 in response to rising demand for ruminant meat and dairy products (IPCC, 2007). Global GHG emissions from dairy production alone are estimated at about 5% of the total (FAO, 2010). As part of its national GHG reduction program, the Canadian government seeks to identify farm management practices that allow for agricultural GHG emissions to be reduced at low cost (AAFC, 2013b). Direct emissions from agricultural production in Canada are estimated at about 10% of the country's total (Environment Canada, 2013), and in the province of Ontario, the dairy sector makes up approximately one quarter of primary agricultural GHG emissions (Jayasundara and Wagner-Riddle, 2014; ECO, 2010). There is a need to identify the means by which GHG emissions from intensive dairy production systems such as Ontario can be reduced at low cost.

There exists significant literature on cost effective GHG mitigation strategies from pastoral dairy production systems. Using a whole farm mechanistic model, Beukes et al. (2010, 2011) find that improvements in both economic and environmental variables are possible on pastoral New Zealand dairy farms through a combination of strategies including diet modification, optimizing nutrient management, and reducing the stocking rate. In another study of pastoral New Zealand dairy farms, Adler et al. (2013) developed a detailed, non-linear optimization model rather than a simulation approach and found that reducing nitrogen fertilizer application was the most cost-effective means of reducing GHG levels by the target of 10%, followed by stocking density changes, with total production costs increasing by approximately the same percentage depending on the farm type. Doole (2014) assesses least cost GHG mitigation methods on a variety of New Zealand dairy farms and finds reducing stocking rate, decreasing nitrogen fertilizer application, reducing supplement use, and improving reproductive performance all to be among the cost effective methods that reduce GHG emissions. In contrast to pastoral systems, dairy production systems in temperate climate regions such as North America and

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http://dx.doi.org/10.1016/j.agsy.2015.03.007
0308-521X/

northern/western Europe involve animals being housed in partial or complete confinement year round, and receiving total mixed rations that tend to be comprised of relatively higher concentrate/supplement levels. These differences in production characteristics, and in particular the high levels of required inputs received off farm, imply that the cost effective systems to reduce GHG emissions will also differ.

Fewer studies exist on GHG mitigation in intensive dairy production systems such as in North America or northern/western Europe. Moraes et al. (2011) assess how rations can be chosen to reduce enteric methane emissions on US dairy farms, and find that a 5% reduction in enteric methane was achieved with a 5% increase in diet costs but a 13.5% reduction GHG emissions required a ration that was 48.5% more expensive than the base formulation. Since grains have approximately 3.5 greater GHG emissions per unit mass relative to forages (Adom et al. (2012), rations that lead to declines in enteric fermentation may result in increased emissions from feed production. Dutreuil et al. (2014) find that total GHG emissions from conventional US dairy farms were reduced by 27.6%, while both maintaining milk production and increasing net return to management by 29.3%, when cows were allowed to graze for part of the year. Although not possible for many intensive dairy-farming systems, the grazing can affect GHG emissions through land use and ration decisions. A shortcoming of Van Middelaar (2014) and the DAIRYDYN model (Britz et al., 2014) that take a life cycle approach to modelling GHG mitigation in the intensive dairy production systems in northern Europe, is that they do not account for the impact of feeding decisions on carbon (C) emissions or removals arising from changes in land use. Schmidinger and Stehfest (2012) note that the implications of land use change arising from livestock feeding decisions can be equal in magnitude to other GHG emission sources from these systems. An exception is Vellinga and Hoving (2011) who apply DAIRY WISE and Introductory Carbon Balance Models (ICBM) to the northern European dairy sector. They report that the loss of soil C from ploughing grassland for maize silage outweighs the declines in enteric methane production achieved from shifting to a higher digestible diet. This finding implies that the impact of feeding decisions on soil C stores from changing land uses should be accounted for in determining preferred abatement strategies within dairy production systems in addition to ration choices. The purpose of this study is to identify the manner in which the management practices related to feeding, namely the formulation of the ration, and the associated land allocation decisions, can contribute to reductions in GHG emissions in intensive dairy production systems.

2. Methods

A bioeconomic model is developed to determine the ration choices and associated crop production decisions that maximize net returns to an intensive dairy farming system subject to GHG emission restrictions. These systems are characterized as confinement feeding operations where animals are housed in barns year round, and receive a high intake of nutrient dense concentrates or supplements. Expenses related to supplying feed represent approximately 70% of total costs for such dairy farmers in the province of Ontario (DFO, 2012). Feed selection also influences the major emission categories from livestock production, namely enteric fermentation, manure, and agricultural soils.

In order to elucidate the cost effectiveness of feeding decisions as a mitigation strategy, we use an optimization model to determine how specific GHG targets can be reached while keeping farm profitability as high as possible. The framework for the model is illustrated in Fig. 1. Developed in GAMS (General Algebraic Modelling System) (Brooke et al., 2008), the one-year, static model is parameterized to represent a typical commercial dairy-crop farm in southwestern Ontario. Characteristics of this farm, such as herd size and productivity, are described in detail in the following section. The farm takes as given exogenous drivers such as the regulatory framework (milk is produced under a supply management regime in Canada), and agro-ecological conditions. The objective is to maximize farm returns, by choosing the formulation of the ration, and associated farmland allocation and feed purchases. Details on how feeds are selected to meet the required nutrient intakes of the animals are given in Section 2.2.

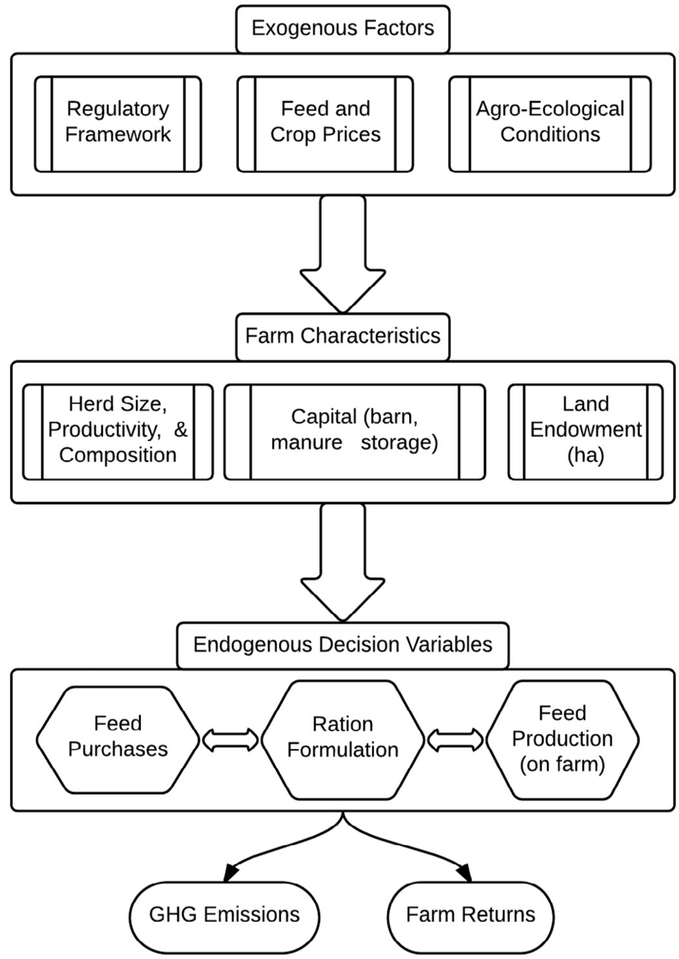

Fig. 1. Analytical framework.

In addition to selecting the ration and land allocation decisions to maximize returns, the model also estimates the GHG levels generated by the resulting farming system. Details on the method for determining emissions minus sequestration for all major processes related to milk production, both on farm and upstream, are described in Section 2.3. GHG emissions/sinks are measured from enteric fermentation, manure, agricultural soils, land use change, and energy consumption. Each of the above emission categories is in some way influenced by the choice of feed on the farm; livestock emissions are directly influenced by the nutrient properties of the ration, while emissions related to feed production are dependent on land allocation and feed purchases, which are themselves dependent on the feeds that are chosen for the ration (see Fig. 2). The model estimates emissions from each of these sources endogenously based on the feeding management decisions. By summing each emissions category, we obtain an estimate of annual net CO_2eq emissions per unit of fat and protein corrected milk (FPCM).