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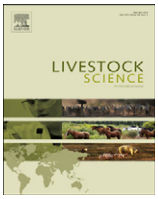

Greenhouse gas emission intensities of grass silage based dairy and beef production: A systems analysis of Norwegian farms

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ABSTRACT

To increase food production while minimizing its influence on climate change, farming systems in future will need to reduce greenhouse gas (GHG) emissions per unit of product (i.e., GHG intensity). To assess the level and variation in GHG emissions intensity among Norwegian dairy farms, we conducted an analysis of 30 dairy farms to calculate farm scale emissions of GHGs, expressed as CO_2 equivalents (CO_2eq) per kg fat and protein corrected milk (FPCM), and CO_2eq/kg carcass weight (CW) sold. A model, HolosNor, was developed to estimate net GHG emissions, including soil C changes, from dairy farms. The model requires farm scale input data of soil physical characteristics, weather, and farm operations. Based on data from 2008 the estimated level of GHG intensity was 1.02 kg CO_2eq kg^{-1} FPCM, 21.67 kg CO_2eq kg^{-1} CW sold as culled cows and heifers, and 17.25 kg CO_2eq kg^{-1} CW sold as young bulls. On average, enteric CH_4 was the largest emission source both per unit FPCM and CW, accounting for 0.39 kg CO_2eq kg^{-1} FPCM, 8.34 kg CO_2eq kg^{-1} CW sold as culled cows and heifers, and 6.84 kg CO_2eq kg^{-1} CW sold as young bulls. Variation in the estimated soil N_2O emissions was the source that contributed the most to the total variation among the farms; the difference between the minimum and the maximum levels was estimated to be 0.30 kg CO_2eq kg^{-1} FPCM, and 6.43 and 6.49 kg CO_2eq kg^{-1} CW sold as culled cows/heifers and young bulls, respectively. Other GHG emission sources also varied considerably among the farms; similar to the N_2O emissions, higher emissions of enteric CH_4, indirect energy use due to manufacturing of farm inputs, and soil C change all contributed to the higher GHG intensity of some farms. Our study estimates large variation in GHG intensity among dairy farms in Norway and indicates a sensitivity of the emissions to mitigation measures. Production of milk and beef is a complex biological system, thus mitigation options are likely to be most successful when applied in small steps. Thus, the most valuable contribution of the current work is the framework of an on-farm tool for assessing farm-specific mitigation options of Norwegian dairy and beef production.

1. Introduction

Livestock production has significant environmental impacts including greenhouse gas (GHG) emissions (Stanford University, 2010). As assessed by IPCC accounting, animal agriculture is responsible for 8–10.8% of global GHG emissions and the emissions are closely related to ruminant numbers, particularly dairy and beef cattle numbers (O'Mara, 2011). There is a growing consensus that global GHG emissions, including those from dairy and beef cattle, will need to be substantially reduced to minimize the risk of unpleasant climate change

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(Godfray et al., 2011). As the global demand of beef and milk are expected to rise 72% and 82%, respectively, by 2050 compared with 2000 (FAO, 2006), GHG emission intensities (i.e., kg CO_2 equivalents [CO_2eq] per unit of food produced) have to be reduced considerably.

The Norwegian Parliament has set targets that will require a reduction in the nation's GHG emissions of 15–17 Gg of CO_2eq by 2020; a 30% reduction from 1990. The agricultural sector is required to contribute 1.2 Gg of CO_2eq to this reduction, which is more than 20% of the sector's current emission (Climate and Pollution Agency, 2010). A significant part of the agricultural contribution is to be achieved through reducing the GHG emissions per unit of milk and beef (Ministry of Agriculture and Food, 2009). As is the case globally, reduction in milk and beef production is not an option, as the population of Norway is expected to increase, albeit at a slower growth rate (20% increase by 2030; Statistics Norway, 2010) than the global average. Norwegian dairy farms are typically small-scale and combine milk production and bull-finishing. Thus, meat (beef) production is mainly a co-product of the dairy industry, with culled dairy cows and young dairy bulls representing the major beef sources. More than 95% of the dairy cows are of the dual purpose Norwegian Red breed, a dairy breed in which beef production capacity accounts for about one-tenth of the combined selection index (Ødegard, 2000). The predominant feeds are timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis*) grass silages complemented by barley (*Hordeum vulgare*) based concentrates.

In general, dairy production is characterized by variation among farms and this variation implies variation in GHG emission intensities (Kristensen et al., 2011; Vellinga et al., 2011). The development and use of simulation models or simpler calculators for estimation of GHG emissions at the farm level has in many countries been useful in detecting tactical mitigation options (i.e., options within a production season that do not require a change of the whole farm strategy; Beauchemin et al., 2010; Christie et al., 2011; Schils et al., 2007). Similar development and use of a whole farm model for estimating GHG emission intensities from Norwegian dairy and beef production would be helpful in identifying suitable GHG mitigation options. Thus, our objectives were to (1) develop a whole farm model for estimating GHG emission intensities of milk and meat production that encompasses the farms' natural resource bases and management; (2) estimate the variation in GHG emission intensities of meat and milk production among Norwegian dairy farms; and (3) identify opportunities for mitigating GHG emission intensities of meat and milk production from Norwegian dairy farms to provide insights pertinent to agricultural policy makers in fulfilling the goals of emission reduction as specified by the Climate and Pollution Agency (2010).

2. Materials and methods

In the following section we first describe the model; thereafter, the farm specific operational and natural resource base data are described.

2.1. The whole-farm model

A farm scale model, the HolosNor model, was developed to estimate net GHG emissions from dairy production systems, including soil C changes, on the basis of robust, reliable, and easily available on-farm data. It is an empirical model based on the Holos model (Little et al., 2008) and the methodology of the Intergovernmental Panel on Climate Change (IPCC, 2006) with modifications that recognize the distinctness of Norwegian conditions. The following GHG sources are considered: enteric CH_4 and manure-derived CH_4 and N_2O; on-farm N_2O emissions from soils; off-farm N_2O emissions from N leaching, run-off and volatilization (indirect N_2O emissions); on-farm CO_2 emissions or carbon sequestration due to soil C changes; CO_2 emissions from energy used on-farm; and off-farm CO_2 and N_2O emissions from supply of inputs. All GHG emissions are expressed as CO_2eq to account for the global warming potential of the respective gases given a time horizon of 100 years: $CH_4\ \text{kg} \times 25 + N_2O\ \text{kg} \times 298 + CO_2\ \text{kg} \times 1$ (IPCC, 2007). The GHG emission intensities are reported as kg CO_2eq kg^{-1} fat and protein corrected milk (FPCM) and kg CO_2eq kg^{-1} carcass weight (CW) sold.

Enteric CH_4 emissions are calculated for each class of cattle according to the IPCC (2006) Tier 2 methodology. Daily net energy requirements for cattle at each stage of production are estimated from energy expenditures for maintenance, activity, growth, pregnancy and lactation as appropriate. The gross energy intake required to meet requirements is then estimated taking into account the energy density of the diet and enteric CH_4 emissions are calculated from gross energy intake using the CH_4 conversion factor ($Ym = 0.065$; IPCC, 2006) divided by the energy content of CH_4 ($55.64\ \text{MJ kg}^{-1}$) (Table 1). The *Ym* is adjusted to account for the digestibility of the dietary dry matter (DM) as suggested by Beauchemin et al. (2010) and Little et al. (2008) (Table 1).

Manure management CH_4 emissions estimates are based on volatile solids (VS) production, according to IPCC (2006), taking into account the gross energy intake of the animal and the digestibility of the diet. The VS production is multiplied by a maximum CH_4 producing capacity of the manure ($Bo = 0.24\ \text{m}^3\ CH_4\ \text{kg}^{-1}$ VS for cows and $0.18\ \text{m}^3\ CH_4\ \text{kg}^{-1}$ VS for heifers and young bulls), a conversion factor from volume to mass ($0.67\ \text{kg m}^{-3}$) and a CH_4 conversion factor specific to the manure management practice (Table 1).

Estimates of direct soil N_2O emissions are based upon the IPCC (2006) emission factor of $0.01\ \text{kg}\ N_2O\text{–N kg}^{-1}$of total N input, defined as the sum of N fertilizer applied, grass and crop residual N, and mineralized N (Table 1). The residue N is calculated as the sum of above ground and below ground residue N (Janzen et al., 2003). The mineralized N is derived from an N:C ratio of soil organic matter of 0.1 (Little et al., 2008). The N_2O emission is strongly affected by soil moisture and temperature conditions (Watts and Hanks, 1978). Relative effects of % water filled pore space of top soil (WFPS) and of soil temperature at 30 cm depth ($ts30\ °C$) are derived from Sozanska et al. (2002) as described by Bonesmo et al. (2012) (Table 1). The seasonal variation in direct soil N_2O

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