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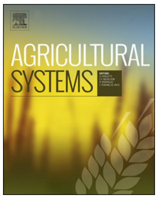

A quantitative assessment of Beneficial Management Practices to reduce carbon and reactive nitrogen footprints and phosphorus losses on dairy farms in the US Great Lakes region

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ABSTRACT

Assessing and improving the sustainability of dairy production is essential to secure future food production. Implementation of Beneficial Management Practices (BMP) can mitigate GHG emissions and nutrient losses and reduce the environmental impact of dairy production, but comprehensive, whole-farm studies that evaluate the efficacy of multiple BMPs to reduce multiple environmental impacts and that include an assessment of productivity and farm profitability, are scarce. We used a process-based model (IFSM) to assess the efficacy of (10+) individual BMPs to reduce the carbon (C) footprint expressed per unit of milk produced of two model dairy farms, a 1500 cow farm and a 150 cow farm, with farming practices representative for the Great Lakes region. In addition to the C footprint, we assessed the effect of BMP implementation on the reactive nitrogen (N) footprint and total phosphorus (P) losses (per unit of milk produced), as well as milk production and farm profitability. We evaluated individual farm-component specific BMPs, that is, 5 dietary manipulations, 3 (150 cow farm) or 4 (1500 cow farm) manure interventions, and 6 field interventions, as well as an integrated whole-farm mitigation strategy based on the best performing individual BMPs. Our results show that reductions in the C footprint expressed per unit of milk are greatest with individual manure management interventions (4–20% reduction) followed by dietary manipulations (0–12% reduction) for both farm types. Field management BMPs had a modest effect on reducing this footprint (0–3% reduction), but showed substantial potential to reduce the reactive N footprint (0–19% reduction) and P losses (1–47% reduction). We found that the whole-farm mitigation strategy can substantially reduce the C footprint, reactive N footprint and total P loss of both farms with predicted reductions of approximately 41%, 41% and 46% respectively, while increasing milk production and the net return per cow by approximately 11% and 27%. To contextualize IFSM predictions for the whole-farm mitigation, we compared components of IFSM predictions to those of three other process-based models (CNCPS, Manure-DNDC and EPIC). While we did observe differences in model predictions for individual flows (particularly P erosion and P leaching losses), with exception of the total P loss, the models generally predicted similar overall mitigation potentials. Overall, our analysis shows that an integrated set of BMPs can be implemented to reduce GHG emissions and nutrient losses of dairy farms in the Great Lakes region without sacrificing productivity or profit to the farmer.

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1. Introduction

Assessing and improving the sustainability (WCED, 1987) of dairy production is essential to meet the nutritional needs of a growing population and to secure future food production. Dairy products represent an important and affordable source of many essential dietary nutrients, including calcium, vitamin D and potassium, which are nutrients of public health concern in the US (Cifelli et al., 2016; Capper and Bauman, 2013; Drewnowski, 2011). Because of their nutritional value, dairy products are included in dietary guidelines world-wide (Capper and Bauman, 2013). Dairy production is, however, a contributor to environmental challenges at local, regional and global scales (Steiner et al., 2006; Pelletier and Tyedmers, 2010; Bouwman et al., 2013).

Dairy production is a source of greenhouse gas emissions (GHG), primarily methane (CH_4) and nitrous oxide (N_2O), and thus contributes to global warming. Dairy production is reportedly responsible for 2.7% of global GHG emissions (Gerber et al., 2010). In the US, the dairy sector is responsible for approximately 1.9% of total US GHG emissions, with enteric CH_4 as the single most important source of GHG emissions, followed by CH_4 from manure management (Thoma et al., 2013). In addition, crop-livestock production systems are the largest cause of human alteration of global nitrogen (N) and phosphorus (P) cycles (Howarth et al., 2002; Boyer et al., 2004; Villalba et al., 2008; Bouwman et al., 2013). Excessive fertilizer application and a relatively low nutrient use efficiency by crops and animals results in large losses of reactive N (any form of N other than N_2) and P to the environment, with repercussions for human health (e.g. secondary particle formation due to ammonia (NH_3) emission and drinking water contamination by nitrate (NO_3^-)) and environmental quality (e.g. eutrophication of lakes and coastal waters and exacerbation of hypoxic zones) (Schindler et al., 2008; Davidson et al., 2011). At a whole-farm scale, generally 15 to 55% of the total N input to the farm (including N fixation and N deposition) and 56 to 74% of the total P input to the farm is converted into edible and non-edible products (e.g. grain, forage, animals and milk) (Gerber et al., 2014; Powell et al., 2017). Most of the remaining nutrients are lost to the environment. Ammonia volatilization due to manure management and soil application of manure is often the largest loss pathway for N, followed by N leaching from soils to the hydrosphere (US EPA, 2014; Powell et al., 2014; Powell and Rotz, 2015). Phosphorus is not volatile and it is primarily lost through erosion and run-off from soils.

Implementation of Beneficial Management Practices (BMPs) can mitigate GHG emissions and nutrient losses and reduce the environmental impact of dairy production. Several BMPs have been developed, predominantly focusing on the mitigation of GHG emissions from individual farm components such as the animal, the manure storage and the field (e.g. Hristov et al., 2013; Montes et al., 2013; Knapp et al., 2014). In dairy production systems, N, P and carbon (C) flows are, however, interrelated; thus, effective mitigation of one pollutant can increase emissions of another pollutant. For example, Dijkstra et al. (2011) suggested that dietary strategies that reduce N excretion from dairy cows may increase enteric CH_4 emissions. Similarly effective mitigation of N losses in one form (e.g. NH_3) is often offset by N losses in other forms (e.g. N_2O or NO_3^-) (Gerber et al., 2013). Field studies have shown that subsurface injection of manure can substantially reduce N losses from NH_3 volatilization relative to broadcast application (~40–98% reduction) (Dell et al., 2011; Duncan et al., 2017), but a portion of that N conservation is offset by increased emissions of the GHG N_2O (~84%–152%) (Duncan et al., 2017). In addition to interactions between N, P and C flows, nutrient flows between farm components, including the animal herd, the manure management system, the field, and the feed, are strongly linked. Altering one component of this nutrient cycle can have major effects on nutrient flows to or from other farm components. To prevent 'pollutant swapping', BMPs should not be evaluated in isolation but rather in a whole-farm context, so that the multiple interacting effects are adequately considered. In addition, on-farm economic cost is an important and often decisive factor in the adoption of any new farming practice. Beneficial Management Practices that jeopardize production (milk, crop yield), and/or are associated with high initial implementation costs and a decrease in long-term profitability are unlikely to be adopted by farmers and as such cannot generally be considered sustainable.

A holistic approach is thus needed that evaluates the efficacy of BMPs to mitigate multiple environmental impacts in a whole-farm context, and that includes an assessment of productivity and profitability (Rotz et al., 2005; Gerber et al., 2013). It is practically and economically infeasible to empirically test all combinations of BMPs at a whole farm scale. Whole-farm process based models are well-suited tools to efficiently test different combinations of BMPs (Rotz et al., 2005; Beukes et al., 2011; Del Prado et al., 2013). These models can account for the underlying physical and chemical processes influencing N, P, and C flows, predict the effect of BMP implementation on milk production and crop yield, and some models (e.g. the Integrated Farm System Model (IFSM)) can account for economic aspects. Process-based models have been employed to test the implementation of BMPs on whole-farm environmental impacts (e.g. Weiske et al., 2006; Dutreuil et al., 2014; Duncan et al., 2017). Most studies, however, have focused on testing the potential of a small set of BMPs to reduce one particular environmental impact, often for a single farm test case. Currently, comprehensive, whole-farm studies that evaluate the efficacy of multiple BMPs to reduce multiple environmental impacts for distinct farm types in different locations, and that include an assessment of productivity and farm profitability, are limited.

Here, we assess the potential of multiple BMPs to reduce the C footprint, reactive N footprint and P loss of two representative dairy farms in the US Great Lakes region, without compromising milk production and farm profitability. Our farms are located in Wisconsin and New York, which are two of the major dairy producing states in the US, together accounting for 21% of the total US milk production in 2016 (USDA ERS). Identifying and quantifying opportunities to reduce farm GHG emissions in these states can help the US Dairy Industry to achieve its (voluntary) commitment to reduce total GHG emissions of the dairy food supply chain by 25% (from 2007 levels) by 2020 (Innovation Center for US Dairy, 2016). Also, Wisconsin and New York are partly located in the US Great Lakes region, where nutrient pollution of surface waters due to agricultural run-off is a long-standing and recurring problem (Robertson and Saad, 2011; Michalak et al., 2013). Yet, agriculture is an important contributor to the economy of both states and retaining these agricultural industries is essential.

The objectives of this study were to: i) evaluate the efficacy of individual BMPs on reducing the C footprint of two representative dairy farms in the Great Lakes region and to simultaneously assess the effect on the reactive N footprint, P loss, milk production and farm profitability and to ii) identify and assess an integrated set of BMPs that can be applied to reduce the C footprint, reactive N footprint and P loss of the production system without sacrificing productivity or profit. The environmental footprints are defined as the effect on the environment expressed per unit of product produced and include an assessment of impacts associated with pre-farm sources (such as the production of purchased feed) (Rotz et al., 2016a). Phosphorus loss represents the total loss of P from the farm to the environment; excluding P losses associated with pre-farm sources.