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Greenhouse gas emissions from liquid dairy manure: Prediction and mitigation[1]

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ABSTRACT

The handling and use of manure on livestock farms contributes to emissions of the greenhouse gases (GHG) CH_4 and N_2O, especially with liquid manure management. Dairy farms are diverse with respect to manure management, with practices ranging from daily spreading to long-term storage for more efficient recycling of manure nutrients for crop production. Opportunities for GHG mitigation will depend on the baseline situation with respect to handling and storage, and therefore prediction and mitigation at the farm level requires a dynamic description of housing systems and storage conditions, and use of treatment technologies. Also, effects of treatment and handling on the properties of field-applied manure must be taken into account. Storage conditions and manure composition importantly define carbon and nitrogen transformations, and the resulting emissions of CH_4 and N_2O, as well as CO_2 and NH_3, which are all important for the GHG balance. Currently, inventories for CH_4 and N_2O emissions from manure are based on emission factors for a limited number of production systems, together with average annual temperature, but the inherent uncertainty of this approach is a barrier toward prediction and mitigation. Although more representative emission factors may be determined at country level, this is both challenging and costly, and effects of management changes for GHG mitigation are not easily quantified. An empirical model of CH_4 emissions during storage is discussed that is based on daily time steps, and a parameterization based on measurements. A distinction between emissions from manure in barns and outside storage facilities is important for assessing effects of treatment technologies, such as anaerobic digestion, where only posttreatment emissions are affected. Upon field application, manure and soil together define the equilibrium distribution of labile carbon and nitrogen between bulk soil and manure hotspots. This introduces heterogeneity with respect to potential for N_2O emissions, which is not represented in existing prediction models. Manure treatment and management options for GHG mitigation are discussed with emphasis on effects on manure volatile solids and N availability. Anaerobic digestion and acidification represent treatment technologies that are relevant for GHG mitigation on dairy farms.
Key words: manure management, methane, nitrous oxide, volatile solids

INTRODUCTION

According to a recent life cycle analysis (Thoma et al., 2013a), the United States' dairy sector is responsible for 1.9% of total national greenhouse gas (**GHG**) emissions, whereas globally this contribution is 3 to 5% (FAO, 2010). Main sources are CH_4 emissions associated with enteric fermentation and manure management, and N_2O emissions from feed and food production, which are therefore also key targets of efforts to quantify emissions and mitigation potentials (Henriksson et al., 2011; Thoma et al., 2013a).

Dairy production systems are extremely diverse with respect to manure management practices and environmental conditions (Sommer et al., 2009; Thoma et al., 2013b), and this will influence the effectiveness of GHG mitigation measures. For example, Sommer et al. (2009) showed that CH_4 emissions from manure in 5 European countries were affected differently by several treatment technologies due to differences in management and storage temperature. Similarly, the 2 states in the United States with the largest dairy herds, California (**CA**) and Wisconsin (**WI**), are different with respect to both climate and manure management practices; a survey found that 50 to 67% of WI dairy farms spread manure year-round without storage, representing on average 45% of the manure volume (Turnquist et al., 2006), whereas this was the case on only 26 to 27% of CA dairy farms in a survey of 2 counties (Meyer et

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al., 2011). As a consequence, the potential for mitigating CH_4 emissions during storage would be greater for CA dairy farms, whereas the potential for improved N use efficiency and, in turn, N_2O mitigation would be greater for WI dairy farms. Effective mitigation strategies thus depend on an accurate description of on-farm conditions.

Contributions from CH_4 and N_2O

Greenhouse gas emissions on dairy farms are dominated by CH_4 and N_2O (Chianese et al., 2009; Kristensen et al., 2011). Even in regions where the number of cows have declined, such as North America and Western Europe, a change toward liquid manure management and extended storage have increased emissions of both gases (Wightman and Woodbury, 2016). The global warming potential (**GWP**) of CH_4 and N_2O are normally considered for a time horizon of 100 yr, and current estimates of GWP_{100} for CH_4 and N_2O are, respectively, 34 and 298 times the GWP_{100} of CO_2 (Myhre et al., 2013). However, CH_4 has a half-life in the atmosphere of only 12 to 13 yr, and thus for a 20-yr time horizon, GWP_{20}, the contribution of CH_4 is 2.5-fold higher at 86, which increases the relevance of CH_4 mitigation efforts to curb global warming in the short term.

Emissions of N_2O are associated with N transformations via nitrification and denitrification under oxygen-limited conditions (Maharjan and Venterea, 2013). Sustained emissions require that aerobic and anaerobic environments exist in close proximity, which may be the case in organic crusts formed during liquid manure storage (Wood et al., 2012), and in solid manure (Webb et al., 2011). Upon field application, factors such as manure composition, application method and soil conditions together determine the potential for N_2O emissions, but given the unpredictable effects of climate, effects of treatment and management can vary dramatically. A recent meta-analysis (Charles et al., 2017) found that liquid and solid organic residues (including manure) are characterized by N_2O emissions that are, respectively, above and below the emission factor currently used by most countries. However, the analysis also found strong positive interactions with soil N status, clay content, and precipitation, indicating that defining local conditions, as for CH_4, is critical for more accurate estimation of emissions.

Gaseous N losses through NH_3, nitrogen oxides (NO_x), and N_2, and leaching losses mainly as NO_3^-, are quantitatively much more important than direct emissions of N_2O (Venterea et al., 2012). Because both NH_3 volatilization and NO_3^- leaching are indirect sources of N_2O, the prevention of these losses through better N use efficiency is an effective strategy for N_2O mitigation.

Objectives

Predicting CH_4 and N_2O emissions from livestock farms is a significant challenge, and currently the uncertainty associated with emission estimates effectively prevents accountability, regulation, and mitigation. Several recent papers and meta analyses have reviewed GHG emissions from manure management and mitigation options (e.g., Hristov et al., 2011; Petersen et al., 2013a; Hou et al., 2015; Jayasundara et al., 2016). In this review, I will instead highlight selected aspects of manure treatment and management that research, from laboratory to practical scale, has shown to be of particular importance for gaseous emissions of carbon (CH_4, CO_2) and nitrogen (N_2O, NH_3). The main emphasis will be on dairy production systems. In view of the many potential interactions between different management stages, the discussion will address both manure management on the farm and subsequent field application.

DRIVERS OF GHG EMISSIONS FROM MANURE

Gerber et al. (2011) reported that the shares of solid and liquid manure management on dairy farms in North America were, respectively, 31 and 36%, whereas the corresponding numbers for Western Europe were 36 and 38%. In many parts of the world, the share of liquid manure management is increasing due to intensification of livestock production (Bouwman et al., 2013) and due to recommendations to store manure to recycle manure nutrients for crop production (Oenema et al., 2011). Because the potential for CH_4 production is estimated to be 4- to 20-fold higher with liquid compared with solid manure management depending on storage temperature (IPCC, 2006), it can be estimated that, for example, in Western Europe liquid manure accounts for >90% of total CH_4 emissions from solid and liquid storage. As stated above, the potential for N_2O emissions after field application is also higher from liquid manure (Charles et al., 2017), and the focus of this review is therefore on liquid manure management. It should be noted, however, that recently introduced deep litter systems also may have a high potential for CH_4 as well as N_2O emissions (Barberg et al., 2007; Galama, 2011).

Storage Environment

An overview of livestock manure handling systems was presented by Sørensen et al. (2013). Collection

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