Journal of Cleaner Production xxx (2017) 1–11

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Evaluating greenhouse gas emissions from dairy manure management practices using survey data and lifecycle tools

Horacio A. Aguirre-Villegas*, Rebecca A. Larson

Department of Biological Systems Engineering, University of Wisconsin-Madison, 460 Henry Mall, Madison, WI 53706, United States

A R T I C L E I N F O

Article history:
Received 28 June 2016
Received in revised form
23 November 2016
Accepted 23 December 2016
Available online xxx

Keywords:
Dairy manure
Survey
GHG emissions
NH_3 emissions
Life cycle assessment
Manure processing

A B S T R A C T

Manure is the second largest source of greenhouse gas (GHG) emissions from dairy farms. Detailed data for representative manure systems are needed to guide climate change mitigation strategies. This study uses surveys sent to WI dairies to identify current farm and manure management practices, collect inventory data on manure handling and energy consumption, compare practices based on farm size, and relate these practices to GHG emissions. Results show that manure systems and management practices vary significantly with farm size. For example, larger farms handle liquid manure and have long term storage while small farms handle solid manure and land-apply daily. Sand separation, solid-liquid separation (SLS), and anaerobic digestion (AD) are implemented only by the surveyed facilities that are large enough to require permitting. Ammonia, biotic, and fossil GHG emissions from archetypes small, large, and permitted facilities are estimated using modeling tools. For this, the most common manure management practices identified by the survey are analyzed. Results (per cow, kg of milk, and ton of manure) show that storing liquid manure for long periods of time without processing contributes the most to GHG emissions. When implementing manure processing, permitted facilities are able to reduce emissions significantly, mostly through AD. Small farms keep their emissions lower than large farms as they mostly handle solid manure and land-apply manure daily. Depending on the practice and farm size, GHG emissions per ton of manure range from 2200 to 12,000 g CO_2-eq for collection, 200 to 2400 g CO_2-eq for transportation, 16,000 to 84,000 g CO_2-eq for storage, and 16,400 to 33,500 g CO_2-eq for land-application.

1. Introduction

Manure is the second largest source of greenhouse gas (GHG) emissions on a dairy farm after enteric methane (CH_4) and is responsible for 7% of both agricultural CH_4 and nitrous oxide (N_2O) emissions (USEPA, 2006). Volatilized ammonia (NH_3) from manure, which can reach up to 70% of excreted nitrogen (N), can travel long distances and deposit into water and terrestrial ecosystems or transform into N_2O emissions, contributing to both eutrophication and climate change (Hristov et al., 2002). Over application of manure can lead to water contamination due to nutrient buildup and subsequent loss and transportation to groundwater or surface water (Burkholder et al., 2007).

Proper design, siting, and sizing of storage structures help prevent manure losses to the environment (Krapac et al., 2002). Controlling the amount and timing of manure application to croplands prevents nutrient buildup and posterior contamination of water streams (Gonzalez et al., 2009). NH_3 losses can be minimized by covering storage systems (Rotz and Oenema, 2006) and by injecting manure, reducing NH_3 emissions by more than 70% after land-application (Hristov et al., 2011). Manure processing such as solid-liquid separation (SLS) and anaerobic digestion (AD) can increase the value of manure streams. SLS effectively removes nutrients, particularly phosphorus (P), along with the manure solids that can be used as fertilizer or bedding (Hjorth et al., 2009). AD can reduce GHG emissions related to manure management by more than 50%, mostly in the form of CH_4 during storage (Amon et al., 2006). When producing electricity through AD, GHG emissions can be further reduced by replacing on-farm fossil fuel-based processes (Aguirre-Villegas et al., 2015a).

Due to their large size and increased manure production, permitted farms (concentrated animal operations that are regulated due to their size >1000 animal units, AU) have a greater

* Corresponding author.
E-mail address: aguirreville@wisc.edu (H.A. Aguirre-Villegas).

http://dx.doi.org/10.1016/j.jclepro.2016.12.133

potential to cause environmental problems than smaller farms. However, some studies suggested that economies of scale and efficient management could put large farms in a better environmental position (Saam et al., 2005). Regardless of size, it is evident that regions with high animal populations, such as Wisconsin (WI), play an important role in protecting the environment from air and water pollution. It is important to understand the representative characteristics of the variety of dairy farms and link the adopted manure management practices to GHG emissions to develop recommendations and policies that limit environmental risks (McCann et al., 2015).

Dairy farm surveys concerning management practices have been conducted in the U.S. Meyer et al. (2011) found that most farms have freestalls for housing and collect manure thorough daily scraping in California. Dou et al. (2001) reported different frequency and manure collection methods among animal types in Pennsylvania. As one of the most important dairy producing states in the U.S., WI has been proactive in conducting surveys. Bewley et al. (2001) targeted freestall dairies and focused on manure collection, bedding, and feed delivery. Cabot et al. (2004) explored the impact of cattle operations on odor and traffic. Powell et al. (2005) surveyed 54 dairy farms across the major soil types to determine the amount of excreted, collected, and uncollected manure N and P. Rowbotham and Ruegg (2015) surveyed 325 dairy farms to identify associations between bedding and milk quality.

Dairy farm practices have been studied, but still, there is a need to develop more specific and detailed up-to-date data. These data are fundamental for lifecycle assessment (LCA) studies and process models that guide policy targets. Specific information, not only regarding manure practices, but other variables such as energy, are needed for these studies as they are responsible for on-farm fossil GHG emissions. The dairy industry is changing fast. Larger and more technological farms are being created in response to market and environmental challenges. Policymakers need updated and representative information related to farm practices to adjust to these changes. This study has the objectives of i) identifying current manure management practices through a survey sent to WI dairy farms; ii) collecting inventory data on energy, and machinery use; iii) comparing practices based on farm size; and iv) relating practices to GHG emissions.

2. Methods

Two steps are adopted to relate GHG emissions to manure management practices. First, a survey sent to WI dairy farms was used to collected primary data on manure handling, machinery power, and time of operation. Second, modeling tools were used to estimate NH_3 and GHG emissions based on these survey data and the equations related to manure presented in the Integrated Farm System Model (IFSM) (Rotz et al., 2015).

2.1. Farm selection and survey description

An anonymous online survey consisting of 106 questions divided into general farm and manure management practices was sent to: i) permitted facilities housing more than 1000 AU (1 AU = 1000 pounds = 454 kg) and, ii) non-permitted facilities. The entire permitted facility population (240 farms) was invited to participate in the study (DNR, 2012). Nearly 2000 non-permitted facilities, out of the 11,063 registered at DATCP (2012), were randomly selected and invited to participate in the study. General farm practices include housing, land for manure application, and milk production. The manure section includes collection, transportation, storage, and land application; anaerobic digestion (AD), solid-liquid separation (SLS), and sand separation (SS). Finally, specific information on machinery power and time of operation has been collected to determine electricity and fuel consumption. To standardize responses, density of manure is assumed to be 1000 kg/m^3 for liquid manure, and calculated at 20%, 15%, and 10% total solids (TS) for solid, semi-solid, and slurry manure respectively (Equation A.1 in the Appendices). The manure characteristics used in this study are presented in Table C.1 (Aguirre-Villegas et al., 2015b).

A total of 143 dairy farmers provided information for analysis. The majority of respondents were distributed across the North East (35%) and West Central regions of WI (30%) (Fig. B1). The response rate was 21% and 5% for permitted and non-permitted facilities, respectively. The low response rate for the latter could be explained by limited internet access and the fact that postcards were sent to dairy farms only once (Buttel et al., 2000). For analysis, farms are classified according to their size in terms of AU into small (1-99 AU), medium (100-199 AU), large (200-999 AU) and permitted facilities ($\geq$1000 AU), based on the reported body weight and animal population (Table C.2).

Median values are reported throughout the text as it provides a better estimate of the central tendency than the mean due to the relatively small sample size and skewness of the data; and mean, median, minimum, and maximum values are reported in the survey result tables (Tables C2 to C7). Both the Pearson chi-squared and the continuity corrected Pearson chi-squared tests (StataCorp, 2011) are conducted for each survey question (see notes of Tables C2 to C.7) to evaluate if the medians across farm size groups are statistically different ($p < 0.005$) from each other. This statistical analysis is most representative for permitted facilities given that 21% of the population of 240 facilities responded to the survey. Responses reached 5%, 2%, and 0.2% of the 962 large farms, 1584 medium farms, and 8277 farms small farms in WI respectively (USDA-NASS, 2012). Results are presented for all four groups of farms but inferences for small and medium farms have to be made with caution due to the small sample size.

2.2. Estimation of GHG and NH_3 emissions from manure management practices using partial LCA tools

A partial LCA model, outlined in detail in Aguirre-Villegas et al. (2014), was used to estimate GHG and NH_3 emissions from biotic and fossil sources during manure collection, transportation, processing, storage, and land-application. This model encompasses all unit-processes from manure excretion to land-application. The model applies literature emission factors and equations related to manure presented in Rotz et al. (2015) to estimate biotic CH_4, N_2O and NH_3 from manure and relates energy consumption to estimate fossil GHG emissions. By using the equations related to manure in this study, the specificities of each manure management practice and the local conditions of WI are captured, facilitating the comparisons among farm sizes and practices.

A detailed explanation of the factors and assumptions used to estimate GHG and NH_3 emissions is presented in Table 1. During collection, CH_4 emissions from manure in the barn depend on ambient temperature and surface area exposed to manure. N_2O emissions are estimated with experimental emission factors. NH_3 emissions depend on ammoniacal N, pH, temperature, and surface area. For manure storage, CH_4 emissions are differentiated for solid and liquid manure. A natural crust is assumed to form on top of the storage for unprocessed manure, but no crust is formed with processed manure as TS are reduced (Rotz et al., 2015). When no crust is formed, no N_2O emissions from liquid manure are assumed (IPCC, 2006a). NH_3 emissions are also affected by this crust formation and depend on the ammoniacal N content in manure. Mineralization rates of 5.2% and 16.5% for solid and liquid manure are assumed