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Research article

# Assessing the effect of different treatments on decomposition rate of dairy manure

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ABSTRACT

Confined animal feeding operations (CAFOs) contribute to greenhouse gas emission, but the magnitude of these emissions as a function of operation size, infrastructure, and manure management are difficult to assess. Modeling is a viable option to estimate gaseous emission and nutrient flows from CAFOs. These models use a decomposition rate constant for carbon mineralization. However, this constant is usually determined assuming a homogenous mix of manure, ignoring the effects of emerging manure treatments. The aim of this study was to measure and compare the decomposition rate constants of dairy manure in single and three-pool decomposition models, and to develop an empirical model based on chemical composition of manure for prediction of a decomposition rate constant. Decomposition rate constants of manure before and after an anaerobic digester (AD), following coarse fiber separation, and fine solids removal were determined under anaerobic conditions for single and three-pool decomposition models. The decomposition rates of treated manure effluents differed significantly from untreated manure for both single and three-pool decomposition models. In the single-pool decomposition model, AD effluent containing only suspended solids had a relatively high decomposition rate of 0.060 $d^{-1}$, while liquid with coarse fiber and fine solids removed had the lowest rate of 0.013 $d^{-1}$. In the three-pool decomposition model, fast and slow decomposition rate constants (0.25 $d^{-1}$ and 0.016 $d^{-1}$ respectively) of untreated AD influent were also significantly different from treated manure fractions. A regression model to predict the decomposition rate of treated dairy manure fitted well ($R^2 = 0.83$) to observed data.



## 1. Introduction

During the past three decades a shift in dairy operations from free grazing to confined animal feeding operations (CAFOs) has raised many questions concerning natural resource contamination (Lanyon, 1994; Spellman and Whiting, 2007). From 1990 to 2011, GHG emission from dairy farms increased by 111% (EPA, 2013). This is mainly due to manure storage in lagoons under anaerobic conditions before application to croplands, emitting non-$CO_2$ GHG emissions, such as methane ($CH_4$), with higher global warming potentials. In the United States, about 37% of the $CH_4$ emission on a dairy CAFO is from manure management due to anaerobic decomposition of dairy manure (USDA, 2011). A shift in manure handling also increased nitrogen (N) losses up to 65 percent (NRCS, 2015), mainly in the form of ammonia, which is a precursor for formation of fine particulate matter (Ndegwa et al., 2008). Dairy manure is usually applied to the nearby fields due to associated cost if hauled to distant locations. As a result, manure nutrients can be in surplus relative to the assimilative capacities of dairy crop lands (Heathwaite et al., 2000; Sims et al., 2005). Losses of these excess nutrients particularly N and phosphorous (P), can cause eutrophication (De Jong et al., 2009; Lanyon, 1994).

In 1999, EPA and USDA jointly issued the Unified National Animal Feeding Operation strategy plan to protect the environment. To help CAFO managers comply with regulations, researchers are studying technological options to reduce GHG emission from manure management. Various traditional and emerging techniques are available for manure treatments to reduce emission and nutrient overloading in dairy lands. From an emissions standpoint,

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anaerobic digestion (AD) has become a common approach to mitigate odor and GHG emissions while also reducing solids content during the biodegradation process (Novak et al., 2011). Post-digestion, the screening of recalcitrant coarse fibers for an additional reduction of solids loading into lagoons (Chastain et al., 2001; Møller et al., 2000), is also a common strategy. Beyond simple coarse solids separation, dairies are also moving to advanced fine solids separation using technologies such as decanting centrifuges, polymer belt press systems, and dissolved air flotation (DAF) (Burton, 2007; Menke et al., 2005). Fine solids separation is credited with significant reductions in organic P and N from the wastewater (Vanotti and Hunt, 1999). Lastly, emerging technologies such as membrane nitrification/denitrification (MBR), vermifiltration, ammonia stripping, ultrafiltration/reverse osmosis, and evaporation are now being considered for incorporation and more complete recovery/removal of nutrients and salts from wastewater (Bao et al., 2012; Fu et al., 2009; Ledda et al., 2013; Uludag-Demirer et al., 2008).

To estimate emissions and nutrient fate from a whole farm perspective, modeling is a viable alternative to expensive, time consuming experimental studies. Models can be used to investigate the impact of manure treatment techniques on gaseous emission and nutrient fate from a whole farm perspective. Different models are available to estimate emissions from manure management and land application (Olesen et al., 2004; Phetteplace et al., 2001; Rotz et al., 2012, 2010; Li et al., 2012; Stöckle et al., 2003; Uslar, 2010). Some of the models use emission factors, while others process-based models uses a decomposition rate constants for carbon mineralization. Literature values for the decomposition rate constant of bovine manure range from 0.011 to 0.072 $d^{-1}$ (Murwira et al., 1990; Saviozzi et al., 1993; Tritt and Kang, 1991). This wide variation is attributed to different manure characteristics including but not limited to ratio of constituents (i.e. proteins, lipids, carbohydrates, and lignin) and prevailing experimental conditions. Manure decomposition rates from the literature are mainly calculated for homogenously mixed manure, without considering the effect of traditional and emerging manure treatments on decomposition rate. The decomposition rate of manure organic matter is dependent on the initial concentration of carbon and its biochemical composition (Thomsen et al., 2013), which is directly related to animal feed composition and solids reduction capacities of treatment units installed on a dairy facility (Møller et al., 2000).

Use of a single decomposition rate constant based on a homogenous manure mixture, therefore, is not likely to predict actual C and N mineralization from a lagoon if AD, solids separation, and nutrients recovery units are incorporated on a dairy CAFO facility. Determination of decomposition rates of treated dairy manure effluents is necessary for planning and optimizing the efficiencies of manure management systems, nutrient fate, and gaseous emission. Although there are many research studies focusing on decomposition rate constants of dairy manure in soils, and biochemical methane production (BMP) under anaerobic condition at higher temperature ranging from mesophilic to thermophilic, there is a lack of research on decomposition kinetics of dairy manure after different treatments and storage in lagoons at ambient conditions.

Dairy CAFO manure composition and treatment techniques may differ from farm to farm, which limits the use of decomposition rate constants calculated for a particular facility. Decomposition kinetics of manure organic matter under anaerobic conditions is a complex and time consuming process and requires up to 90 d or more incubation time (Kafle and Kim, 2012). Mathematical models with fast analytical methods allow quick prediction of decomposition rate constants and are very useful for predicting the BMP and biodegradability of biomass used in renewable energy production (Chandler et al., 1980; Lesteur et al., 2011). Since knowledge of the decomposition rate of dairy manure subject to different treatments is important for predicting gaseous emission from lagoons, development of a model for determining decomposition rate of treated manure, based on its constituents, greatly improves the accuracy of emissions predictions, without undertaking costly experiments.

To the best of our knowledge, this is the first study to examine the impact of traditional and emerging manure treatments on the decomposition rate constants of dairy manure. The main objective of this study was to evaluate the impact of different manure treatment techniques on decomposition of dairy manure effluents stored in lagoons under anaerobic conditions. The specific objectives were: (1) to derive the first order decomposition rate constants for single and three-pool decomposition models, and (2) develop an empirical model to predict the decomposition rate constant for single pool carbon kinetics.

## 2. Materials and methods

### 2.1. Manure source

Manure samples were collected at various points in the manure processing system in a commercial dairy operation located in Outlook, WA, USA. Fig. 1 shows manure flow through different treatments and identifies the points where manure samples were collected. Grab samples at each point were collected when the entire system was operating at steady state (i.e. during representative flow across all of the unit operations inlet and outlets). Samples were collected in 5-gallons buckets, labeled, sealed and stored in 4 °C a walk-in cooler. During later analysis, material in buckets were thoroughly mixed and sub-sampled into 2 L polyethylene bottles and stored at 4 °C before analysis. Manure fractions included untreated AD influent (UT, 50% diluted as-produced manure); AD effluent, which was divided into two fractions, effluent containing only suspended particles (AD-liq) and settled solids removed from the AD effluent (AD-sett); screen-separated digested coarse fiber (CF); fine solids resulting from advanced solids DAF separation (FS); and effluent post AD, screen and DAF separation (CF/DAF-liq). AD suspended and settleable solids were separated following the methodology used in Frear et al. (2011). UT, AD-liq, CF/DAF-liq and AD-sett were considered to be liquid/slurry fractions while CF and FS were considered to be solid fractions.

### 2.2. Analytical methods

Total solids (TS, 2540B) and volatile solids (VS, 2540E) were determined according to standard procedures outlined in APHA (2005). Total ammonia nitrogen (TAN) and Total Kjeldahl nitrogen (TKN) were analyzed using a Tecator 2300 Kjeltec Analyzer (Eden Prairie, MN, USA). Structural carbohydrates and lignin were determined using the National Renewable Energy Laboratory Analytical Procedure NREL/TP-510-42618, while lipids were measured following the protocol described by Hara and Radin (1978). Protein was determined by subtracting TAN from TKN and multiplying by a factor of 6.25 (Pham et al., 2013). Total Carbon (CT) and N in manure fractions were determined using a TruSpec CHN analyzer (LECO, UK); resistant carbon (Cr) was determined by first performing acid hydrolysis on dry mass (Sollins et al., 1999) and then analyzing the hydrolysate for C using the TruSpec CHN analyzer. Biogas composition was analyzed using a gas chromatograph (GC) CP-3800 (Varian Inc, CA, USA) fitted with SilicaPLOT 50 m × 0.53 mm × 4 μm and HayeSep Q 80/100 Mesh Silcosteel 18′ × 1/8″ columns.