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Research article

Life cycle assessment of superheated steam drying technology as a novel cow manure management method

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A R T I C L E I N F O

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A B S T R A C T

Common methods of managing dairy manure are directly applying it to the farm field as a fertilizer. For direct application without any type of treatment, the majority of nutrients in the manure run off to the local river and lake during precipitation periods. The algae bloom is one of the environmental outcomes due to eutrophication of the lakes, which may jeopardize the quality of drinking water. In this study, superheated steam drying (SSD) technology is investigated as an alternative manure management method. Rapidly dried cow manure can be used as alternative fuel. Evaluations of energy payback time (EPBT) and life cycle assessment (LCA) of the SSD technology are presented in the SSD scenario and the results are compared with those of the direct field application (FA) of fresh manure and anaerobic digestion (AD). The heat required for the generation of superheated steam in the SSD scenario is provided from combustion of the dry manure to reduce energy costs. The results for the SSD process show 95% and 70% lower eutrophication and global warming potential in comparison to the FA scenario. Acidification potential for SSD turned out to be 35% higher than FA. The comparison of SSD with AD for their EPBT and normalized impacts indicated that the proposed SSD scenario has higher environmental sustainability than AD (70% lower impact), and is likely an economically better choice compared to conventional AD method (87% lower EPBT) for the future investment.

1. Introduction

Dairy operations are becoming more industrialized and causing greater environmental impact at the same time (De Vries et al., 2012). In the U.S. most of the small farms with open animal grazing have already been converted to larger confined animal operations (CAFOs). While manure was seen as an asset and managed without problems in smaller farms, the large volumes of manure from CAFOs is now a liability for farmers (Centner, 2006). Many dairies spread manure on fields during winter as a fertilizer (Moore and Ippolito, 2009). Land application of manure without any treatment threatens the surroundings due to high concentrations of organics, ammonia and other toxic pollutants (Shalini and Kurian, 2012). From the manure applied to fields, nutrients, pathogens, and other contaminants seep into the soil and reach drinking water sources threatening the public health and the environment (Williams et al., 2016). The growth rates of microalgae and algae in surface waters increase as the soluble nutrients such as nitrogen and phosphorus become available in the water (Hanifzadeh et al., 2012). Local communities are directly experiencing the eutrophication impacts resulting from manure nutrients reaching surface waters (Bennett et al., 2001). For example, in Northwest Ohio 370 million pounds of manure are produced from the 37,000 dairy cows (OSU, 2006). Nitrogen and phosphorus runoffs from CAFO manures are estimated to be a large contributor to the algal blooms in Western Lake Erie Basin, of which toxins pass through drinking water treatment facilities and resulted in a drinking water ban in Toledo for three days in 2013 (Ho and Michalak, 2015). While the local runoff problems receive greater attention, manure is also a source of air emissions of methane, nitrous oxide and ammonia that cause global warming, acidification and eutrophication at

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regional and global scales (Smith et al., 2009; Solomon et al., 2007). In the United States, total global greenhouse gas (GHG) emissions in 2014 amounted to 6,870 million metric tons (MMT) of carbon dioxide equivalent and 9% of this amount was from agricultural emissions (USEPA, 2016).

One approach to reduction of the environmental impacts from manure runoff is to treat manure prior to land application. Treated manure can increase the nutrient uptake by crops and reduce runoff problems (Daniel et al., 1994). Anaerobic digestion (AD) is the most common method of manure treatment prior to land application (Macias-Corral et al., 2008). The main challenges for AD are long retention time and slow start-up (Poh and Chong, 2009). Moreover, AD has significant capital and operational costs and is not economically viable unless energy and fertilizer can both be sold (Franchetti, 2013).

Development of a more efficient manure treatment process is necessary to reduce the cost and environmental impacts of manure management. A rapid conversion process could possibly make holding ponds and storages unnecessary and help reduce runoffs. In this study, we address this problem by analyzing an alternative method for management of manure in which fresh manure is first dried using superheated steam drying (SSD) and then combusted as a solid biofuel. This method takes advantage of highly energy-efficient SSD technology (Fitzpatrick, 1998). The manure biosolids produced from the dryer has about 20 MJ/kg on a dry weight basis, which is similar to the energy content of low-grade coal (Liu and Tsai, 2016). So, the manure biosolids can be used to regenerate superheated steam for the drying process by heating up the spent steam from the output of dryer chamber. We evaluated the environmental performance of this technology using Life Cycle Assessment (LCA). Global warming potential (GWP), eutrophication potential (EP) and acidification potential (AP) were used as the indicators for environmental impacts. An energy evaluation of this technology (as a proxy for economic analysis) was also performed and payback time period was reported and compared to AD.

2. Methods

2.1. Description of the systems

Two different scenarios for management of cow manure were modeled for their environmental impacts: 1) Scenario 1 is for direct application of manure on the fields (FA), and 2) Scenario 2 represents rapid drying of manure using the SSD process. In addition, we compared the results from these two scenarios to literature data for AD.

The direct application of cow manure (Scenario 1) is a commonly used method for manure management as it needs low investment and the effluent is a worthy source of nutrients for crops. The first scenario is depicted in Fig. 1. The process of land application consists of two steps; storage of manure in open ponds (located within a dairy farm) for a long period of time (yearly storage was assumed in this study) and its subsequent application on land as a fertilizer.

The schematic of the SSD scenario (Scenario 2) is shown in Fig. 2a. In the SSD scenario, cow manure is stored for a short period of time (weekly storage is assumed in this study) and then transferred from a dairy farm to a drying plant. The drying plant is assumed to be located at the center of northwestern Ohio region.

Fig. 2b indicates the schematic of dryer operation. During the drying process, the enthalpy of superheated steam decreases and when leaving the dryer, the steam becomes saturated steam. The saturated steam exiting the dryer may also be applied to a turbine for electricity generation. However, in our study, the used steam is recycled to the boiler to be heated to a superheated state for the next drying process. Combustion of the dried manure is the main source of heat to generate the superheated steam. The combustion residual and heat are the products of the combustion. The residual of combustion (about 15 wt% ash) was not included in our analysis.

2.2. Goal and scope definition

The objective of this study is an environmental assessment of two different cow manure management methods for dairy farms located in northwestern Ohio. The treatment of cow manure and its conversion to a value-added product as a fertilizer or energy source was assumed as the functions of the treatment system. The functional unit selected for the comparison of the two scenarios was the use of 1 m^3 of cow manure.

The flowcharts for the direct application scenario and the SSD scenario are shown in Figs. 1 and 2, respectively. The boxes in the dashed line represent the processes that are not included in the study. Because the dryer is located away from the dairy farm while the agricultural land is usually located nearby open ponds, the transportation in the FA scenario is neglected in comparison with the SSD scenario. Moreover, loading and unloading of manure from

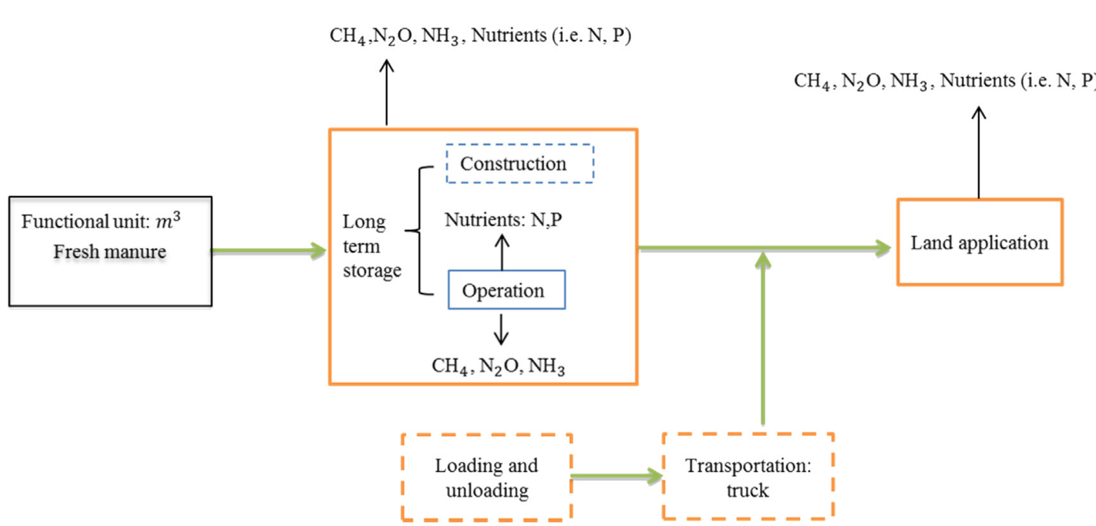

Fig. 1. Flowchart of the first scenario (FA); dashed line represents the processes which were not considered in this study.