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Life cycle assessment of greenhouse gas emissions of feedlot manure management practices: Land application versus gasification

Hanjing Wu [a,b], Milford A. Hanna [a,b,*], David D. Jones [b]

[a] Industrial Agricultural Product Center, University of Nebraska-Lincoln, 211 L.W. Chase Hall, Lincoln, NE 68583, USA

[b] Department of Biological Systems Engineering, University of Nebraska-Lincoln, Lincoln, NE 68583, USA

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ABSTRACT

Animal waste is an important source of anthropogenic GHG emissions, and in most cases, manure is managed by land application. Nevertheless, due to the huge amounts of manure produced annually, alternative manure management practices have been proposed, one of which is gasification, aimed to convert manure into clean energy-syngas. Syngas can be utilized to provide energy or power. At the same time, the byproduct of gasification, biochar, can be transported back to fields as a soil amendment. Environmental impacts are crucial in selecting the appropriate manure strategy. Therefore, GHG emissions during manure management systems (land application and gasification) were evaluated and compared by life cycle assessment (LCA) in our study. LCA is a universally accepted tool to determine GHG emissions associated with every stage of a system. Results showed that the net GHG emissions in land application scenario and gasification scenario were 119 and -643 kg CO_2-eq for one tonne of dry feedlot manure, respectively. Moreover, sensitive factors in the gasification scenario were efficiency of the biomass integrated gasification combined cycle (BIGCC) system and energy source of avoided electricity generation. Overall, due to the environmental effects of syngas and biochar, gasification of feedlot manure is a much more promising technique as a way to reduce GHG emissions than is land application.

1. Introduction

Greenhouse gases (GHGs) effectively absorb thermal infrared radiation, emitted by the Earth's surface, the atmosphere itself, and clouds. The heat trapping process within the surface-troposphere system by GHGs is called the greenhouse gas effect [1]. Naturally occurring GHGs include water vapor, CO_2, methane (CH_4), nitrous oxide (N_2O), and ozone (O_3) [1,2]. The increase in GHG concentration has been accepted widely as the major cause of current global warming, and animal manure is an important source of GHG [3]. In 2010, CH_4 emissions from manure management represented about 8% of total CH_4 emissions from anthropogenic activities, and manure management also was a small source of N_2O emissions [2].

Land application is the most common way to use animal manure, with the purpose of using manure nutrient as the fertilizer. Around 83% of feedlot manure typically is processed by land application [4]. However, applying feedlot manure to

* *Corresponding author*. Department of Biological Systems Engineering, University of Nebraska-Lincoln, 211 L.W. Chase Hall, Lincoln, NE 68583, USA. Tel.: +1 402 472 1634; fax: +1 402 472 6338.
E-mail address: mhanna1@unl.edu (M.A. Hanna).
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the surrounding cropland may become unsustainable for large feedlots, as it can exceed the carrying capacity of local ecosystems leading to environmental and health concerns [5]. Gasification is an alternative way to manage animal waste. The principle of gasification is to decompose organic matter into useful energy such as syngas. In order to generate electricity and heat, syngas produced from gasification could be utilized in energy conversion devices, such as boilers and gas turbines. For small-scale power plants, typically syngas is combusted in a stationary IC engine with a generator and provisions for heat recovery. For larger scale operations, integrated gasification/combined cycle (IGCC) technology can be applied to generate electricity and heat [6]. Further, biochar, as the byproduct of gasification, has attracted growing interest globally as a soil amendment [7]. However, the nutrient value of biochar differs considerably due to the variation among the feedstock characteristics and gasifier operating conditions [8].

GHG emissions are a major factor when selecting the appropriate animal waste management practice and life cycle assessment (LCA) is a universally accepted tool to determine GHG emissions due to its “cradle-to-grave” approach [9]. LCA has been adopted to analyze emissions of GHG for different animal waste management systems. For example, Morrie et al. [10] conducted a LCA for anaerobic digesters on small dairy farms. Also, environmental effects of composting dairy manure were evaluated by Hishinuma et al. [11] by means of LCA. Nevertheless, not much information can be found related to feedlot manure management in terms of GHG emissions. Therefore, the aim of this research was to estimate GHG emissions of feedlot manure management systems (land application and gasification) by LCA. In the land application scenario, feedlot manure was collected, stored and applied as fertilizer onto the field. In the gasification scenario, feedlot manure was gasified to produce syngas and biochar, which were used as the power source and soil amendment, respectively.

2. Methodology

2.1. Goal and scope

The goal of this study was to evaluate GHG emissions of two feedlot manure management strategies: land application and gasification. The function unit was one tonne of dry feedlot manure. Emissions of each GHG were converted into carbon dioxide equivalents (CO_2-eq), which were calculated by multiplying their respective global warming potential (GWP) by the specific mass of each GHG. The GWPs of CH_4, and N_2O were 25 and 298 times that of CO_2 on a mass basis, respectively, based on a 100 year horizon [12].

2.2. System boundaries

System boundaries of the two manure management practices are shown in Fig. 1 and 2, respectively. In land application scenario, feedlot manure was collected twice a year (winter and spring), stockpiled and land applied in the fall. The avoided process was the commercial fertilizer utilization due to the manure application. In the gasification scenario, feedlot manure was collected every two months (six times a year). The collected manure was transported to an industrial-scale gasification plant. The technology of biomass integrated gasification combine cycle (BIGCC) was used to generate electricity. Biochar produced from gasification plant was transported back to the field as a soil amendment. Avoided processes were electricity generation from fossil fuel power plant, and fertilizer utilization due to biochar application.

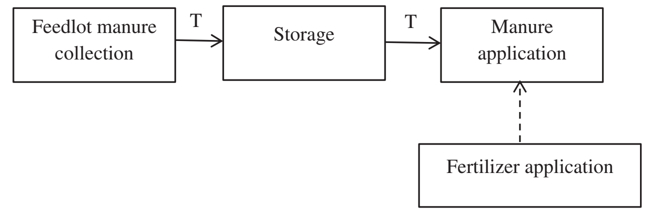

Fig. 1 – LCA boundary of land application system of feedlot manure (T stands for transportation and dashed arrows stand for avoided process).

2.3. Data inventory and major assumptions

To make the industrial-scale gasification plant possible (the feeding rate was 1 tonne of dry manure per hour), assuming the feedlot manure was provided by 10 feedlots, each with 500 animal-units (AU). AU was defined as a 454 kg cow or its equivalent [4]. The inventory data were based on the literature references and GREET Model 2012 (Argonne National Laboratory, USA) [13]. Note that emissions from the manufacture of the transportation tools were out of the consideration in this study. In addition, the biogenic CO_2 emissions were not taken into account, because carbon from biomass is part of the natural carbon cycle. The sections below include detailed information of data sources and assumptions for each life cycle stage.

2.4. Feedlot manure characteristics

Characteristics of feedlot manure vary widely due to factors of climate, diet, feedlot surface and cleaning frequency [4]. The excreted manure is usually high in moisture content and low in ash content. On the other hand, for collected feedlot manure, water concentration drops because of evaporation, and the fixed solid increases due to its incorporation into the soil. Table 1 shows the characteristics of feedlot manure used

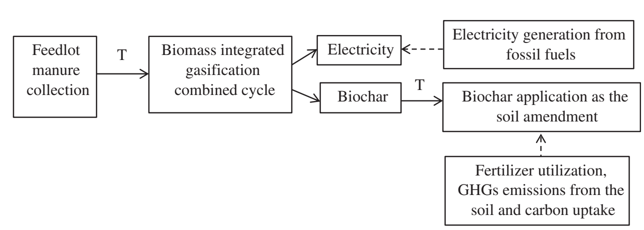

Fig. 2 – LCA boundary of gasification system of feedlot manure (T stands for transportation and dashed arrows stand for avoided process).