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Pyrolysis-Biochar for Sustainable Dairy Farms

Eunsung Kan[1,2*]

[1]*Texas A&M AgriLife Research Center, USA*

[2]*Tarleton State University, USA*

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[*]**Corresponding author:** Eunsung Kan, Texas A&M Agri Life Research Center, Stephenville, Texas, USA, Tel: 1-254-968-4144, Fax: 1-254-968-3759, Email: Eunsung.kan@ag.tamu.edu

Abstract

Current dairy manure management showed several limitations threatening sustainability of dairy farms. Land application caused significant pollutions in water, soil and air and shortage of water resources. Anaerobic digestion suffered from low yields of methane and fluctuating performance while composting revealed its limited efficiency for scale-up. Pyrolysis of dairy manure revealed high potential to replace current manure management while producing energy, bio-oil and biochar. Biochar from pyrolysis of manure presented promising applications such as alternative fertilizer, recovery of nutrients and removal of toxic contaminants. Therefore, environmental application of biochar integrated with pyrolysis of manure could significantly enhance environmental sustainability at dairy farms.

Keywords: Manure management; Land application; Composting; Anaerobic digestion; Pyrolysis; Biochar

Introduction

Dairy farms like other animal farms have multiple threats against its sustainable operation such as significant pollution, food safety, water shortage and energy supply [1]. Current management of dairy manure is land application which have caused significant pollutions in water, air and soil [2]. High levels of nutrients such as nitrogen and phosphorus in manure are often released to environments and lead to significant contamination of various water resources, algal bloom occurrence and nitrate accumulation [3]. Release of untreated antibiotics and hormones from dairy manure have been increasing concerns in evolution of antibiotic resistant bacteria, endocrine disrupting activity and biotoxicity [4]. High level of nitrous oxide (N_2O), one of major greenhouse gases, is emitted from soil amended with manure via nitrification and denitrification [1]. Unpleasant odors and methane are also released from manure during its land application [5,6]. In addition, manure applied to soil also increases soil acidity and degradation with significant reduction in diversity of soil microbial community ultimately decreasing agricultural productivity [2].

Composting can produce biofertilizers via microbial actions using dairy manure. However, it causes drastic loss of ammonia and development of odors during composting process [5,6]. Composting efficiency heavily relies on supply of oxygen for aerobic bacterial actions which significantly has limited its practical application for scale-up. Practical design of composting process needs to include appropriate aeration manners and reactor volume enough to support efficient aeration to microbes requiring high capital and operating costs for scale-up.

Recently anaerobic digestion has been suggested to resolve manure disposal, energy recovery and greenhouse gas control. Anaerobic digestion (AD) is an attractive and widely used process that maximizes microbial metabolic abilities to convert organic fraction of wastes to biogas. Operation of closed bioreactors for AD can prevent emission of greenhouse gases and odors. A variety of research to date evaluated the effects of various manure Kafle & Chen [7], inoculum to substrate (ISR) [8], pretreatment [9], and temperature [10] on biogas production potential. However, the AD of manure often suffered from low methane yield and process instability. It was found the anaerobic digestion of dairy manure suffered low yield of methane, fluctuating performance, and significant amounts of undigested sludge after the digestion.

Alternative to these technologies, thermal disposal of manure such as pyrolysis has been actively studies because the thermal processes are linked with on-site energy recovery, better water quality and production of biochar as a valuable product for agricultural and environmental applications [11,12]. Pyrolysis produces syngas, bio-oil and biochar at various yields under different conditions and feedstocks [13]. Pyrolysis could be used as an economical management of dairy manure to effectively dispose manure and reduce environmental problems associated with current manure management while producing valuable products such as biochar and bio-oil. Recently biochar generated from pyrolysis of dairy manure has gained drastic interests due to its multiple benefits including increase of carbon sequestration, soil fertility, nutrient retention and water use efficiency and decrease of greenhouse gas emissions [11,12]. Biochar production yield is highly affected by feedstock (e.g. physical and chemical properties) and operating conditions (e.g. heat transfer, peak temperature, and residence time) [14]. For example, slow pyrolysis (minutes to hours) could produce 30~50% bio-char, while fast pyrolysis (less than two seconds) produces a lower amount of bio-char (10~20%) with different properties.

Up to date various biochars have been amended to soil for enhancing soil fertility, microbial community, and crop yields. Biochar from a wide range of sources has been promulgated as a soil amendment with positive effects on target plants [11,12]. For example, biochar in soil retained high moisture, nutrients and organic carbon which are essential compounds for plant growth while positively influencing on plant growth [15].

Recovery of phosphate on biochar has received increasing attention compared with other methods since biochar could be an effective and economical adsorbent for removal of phosphate from wastewater including dairy effluents [11]. Biochars from various feedstock and metal oxide-decorated biochars have shown promising performance for recovery of phosphate from wastewater mainly owing to effective interactions with phosphate via surface complexation and electrostatic interaction [16].

Recent reports on the recurrent detection of antibiotics residues from wastewater treatment facility effluents, soils, sediments, and aquatic environments have raised concerns for global public health [2]. The spread of these antibiotics can potentially lead to long-term adverse consequences on various ecosystems, including acute and chronic toxicity and propagation of antibiotic resistance in microbes. While current treatment methods for antibiotics in water have showed limited performances, removal of antibiotics in water using biochar has shown potential adsorption process since biochar from various feedstock at different pyrolytic conditions could provide effective functionality to capture antibiotics from wastewater and water [17]. Compared with the pristine biochar, the activated biochar has shown excellent adsorption of antibiotics in water. The biochar derived from various biomass was activated via physical (i.e., steam) and chemical (i.e., alkaline solutions, catalysts) methods in order to increase surface area and enhance porous structure. Current results indicated the activated biochar would be highly promising for removal of antibiotics in wastewater.

Conclusion

In overall, pyrolysis of dairy manure integrated with biochar technology would be highly effective and economical process for enhancing environmental sustainability at dairy farms while contributing to pollution in water, soil and air from dairy manure. Further studies will include systematic analysis (i.e., water-energy-food nexus) of integrated pyrolysis-biochar process at dairy and other animal farms.

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