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Review

Struvite recovery from anaerobically digested dairy manure: A review of application potential and hindrances

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ABSTRACT

Anaerobically digested dairy manure is rich in ammonium, orthophosphates, and magnesium, indicating a high potential for struvite recovery. Continuous generation of large amounts of dairy manure plus increasing global interest in anaerobic digestion of dairy manure suggest a huge market for struvite production with anaerobically digested dairy manure. However, the complex chemical composition of digested dairy manure presents hindrances to struvite recovery. This review paper assesses the significance and potential of struvite recovery from anaerobically digested dairy manure, identifies the factors hindering struvite recovery, and discusses the methods to overcome hindrances and the measures to improve phosphorus speciation of dairy manure for struvite formation. This paper proposes using "struvite recovery potential" or $P_{struvite}$ based on the least molar activity of struvite component ions in addition to "supersaturation ratio" to identify the potential for struvite recovery. The probable hindrances mainly include high Ca^{2+} concentration and molar activity ratios of Ca^{2+}: Mg^{2+} and Ca^{2+}: PO_4^{3-}, high ionic strength, and high alkalinity. Struvite formation and purity is likely a function of all the interfering variables, rather than just a single factor with digested dairy manure. Potential enhancement measures need to be tested for technical and economic feasibility and applicability to various sources of digested dairy manure. This review paper provides guidance to overcoming the hindrances of digested dairy manure to struvite formation.

Contents

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1. Introduction

1.1. Environmental concerns with manure management

Animal feeding operations generate large amounts of liquid manure, which is a mixture of as-excreted manure, used bedding, and wastewater. Liquid manure contains high concentrations of nitrogen and phosphorus (ASABE, 2010). It is typically spread or injected to cropland as an organic fertilizer, directly or after treatment in anaerobic digesters or lagoons (ASABE, 2010; USDA, 2009). Manure application rates that are based on crop nitrogen requirements generally result in excessive phosphorus application because phosphorus (P) to nitrogen (N) ratio of animal manure is typically high relative to agronomic requirements (Cordell et al., 2009; Harris et al., 2008; Vitti and Kebreab, 2010). Over-application of dairy manure to cropland adds pollutant loading to nearby surface water and groundwater. Under the Clean Water Act, CAFOs in the U.S. are defined as point source dischargers. The 2008 CAFO Rule requires a CAFO that discharges or proposes to discharge pollutants to surface water to apply for a National Pollutant Discharge Elimination System permit and submit a nutrient management plan (NYSDEC, 2014; U.S. EPA, 2008). Moreover, animal manure contributes to air pollution through volatilization of free ammonia in animal housing, manure storage and treatment facilities, and manure-applied fields. CAFOs are a major source of ammonia emission (Hristov et al., 2011; Vaddella et al., 2013).

Excess manure needs to be either transported offsite or treated onsite. High transportation costs, seasonal application needs, odor concerns, and the potential liability of environmental impacts limit the feasibility of offsite transportation and discourage other farmers from using manure (Howland and Karszes, 2014; Ribaudo et al., 2003). Under the increasingly stringent permit requirements in the national and state Pollutant Discharge Elimination Systems (NYSDEC, 2014; U.S. EPA, 2008), many dairy farms in the U.S. are seeking technologies to upgrade their manure management plans while turning manure into valuable products (Fig. 1).

Anaerobic digestion is increasingly applied to stabilize organic matter in liquid manure and recover energy from biogas (USDA, 2009; U.S. EPA, 2010, 2015). Treating dairy manure by anaerobic digestion has additional benefits, such as solids reduction, reduction of greenhouse gas emissions, odor control, and pathogen reduction. Anaerobic digestion converts organic N and P to inorganic ammonia and orthophosphates, which are readily available for uptake by crop plants. Due to more readily available ammonia and orthophosphates in anaerobically digested dairy manure (ADDM), the risk of over-fertilization and environmental impacts is increased when ADDM is applied to land at rates typical for organic fertilizers such as undigested dairy manure (Nkoa, 2014; Uludag-Demirer et al., 2008). In order for anaerobic digestion to be a viable and sustainable energy source, digester effluent must be treated.

Typically, P in wastewater is removed biologically using P-accumulating bacteria or chemically through precipitation by adding metal salts (Metcalf & Eddy/AECOM, 2014). Chemical precipitation introduces high costs, requires skilled operators, and yields a large amount of chemical sludge to dispose of. Biological processes remove P by wasting sludge. The high concentration of suspended solids further limits the technical feasibility of wastewater treatment methods for ADDM. Because of these constraints, conventional wastewater treatment methods are unattractive options for CAFOs. In recent years, attention has been paid to energy production via anaerobic digestion followed by resource recovery (Fig. 1) such as struvite production from digested dairy and cattle manure (Huchzermeier and Tao, 2012; Moerman et al., 2009; Uludag-Demirer et al., 2005, 2008; Zeng and Li, 2006; Zhang et al., 2010). Struvite crystals can be directly land-applied for crop cultivation or lawn care. Relative to direct land application of

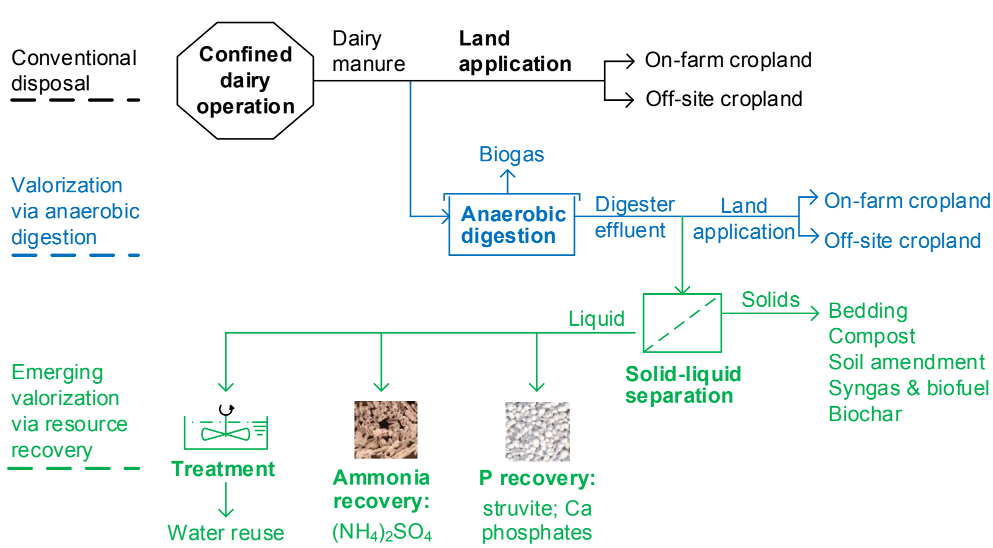

Fig. 1. Evolution of on-farm dairy manure management strategy.