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Techno-economic optimization of community-based manure processing

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ABSTRACT

This study investigates community-based processing of manure to produce organic fertilizer using granulation. We developed a mixed-integer optimization model to determine the minimum sale price of granulated manure, i.e., price corresponding to zero net present value (NPV = 0). We used dairy farms inventories for two regions in Wisconsin to develop case studies to evaluate community-based processing. Minimum sale price of granulated manure varied between $360 and $460 per ton based on the region and the imposed aggregation radius. Granulation facilities were located on the farm with the largest herd in each case. Selection of farms for participation in granulation facility relied on both proximity and herd size. Sensitivity analyses were performed to analyze the impacts of market changes and subsidies on the investment. Community-based manure processing was found to offer an opportunity to facilitate processing and export of nutrients due to economies of scale advantage.

1. Introduction

Waste management is a major challenge facing livestock and poultry producers today. As production transitions toward consolidation and regional concentration, producers have fewer options for the economic utilization of manure. Typical management involves seasonal manure hauling from livestock and poultry growing facilities to apply on nearby crop and hay fields. Field application of manure follows agronomic guidelines to ensure that growing crops receive sufficient nutrients with a minimum surplus. Manure over-application, beyond crop needs, has been shown to increase nutrient losses, through leaching and runoff, to surrounding ground and surface water (Ribaudo et al., 2003). Such nutrient losses lead to the degradation of water quality expressed as increased turbidity, toxicity, fish kills, and algal blooms resulting in significant economic and environmental losses (Carpenter et al., 1998). Regions with high density of livestock and poultry production such as Chesapeake bay, Central Iowa, Southeastern North Carolina, and Illinois River Watershed (IRW) in Arkansas-Oklahoma are utilizing various watershed-level approaches to ensure water quality improvements (Kleinman et al., 2015). In the context of livestock production, such measures involve the establishment of manure storages that can accommodate seasonal waste volumes without risk of spills or runoff (Sharara et al., 2017). The use of nutrient management plans is also encouraged (or mandatory if the facility exceeds a size threshold) to facilitate proper nutrient utilization (Osmond et al., 2015). A key challenge to producers in regions of intensive livestock production, however, is the decreased availability of nearby fields to accommodate manures. Increased herd sizes and the decreased cropland are continuously shifting the nitrogen and phosphorus balances in these watersheds toward positive nutrient surpluses (MacDonald and McBride, 2009; U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS), 2015). Furthermore, historic buildup of phosphorus (P) in these watersheds mean that legacy P delivery will continue to challenge water quality improvement (Sharpley et al., 2013).

Nutrient export can be a useful approach to remedy nutrient imbalances. A litter export program was implemented in the Illinois River Watershed (IRW) and successfully reduced poultry litter inputs in the watershed by 70%. Such approach, however, can be challenging in hog and dairy production regions. Unlike poultry litter, hog and dairy manures have a water content ranging from 85% and 95%. Transportation of water-rich manure is uneconomic and increased traffic from its transport can lead to road deterioration. Advanced manure processing can reduce undesirable manure characteristics such as water content, odor, and pathogens and generate a stable, shippable product with a positive economic value beyond nutrient removal from nutrient surplus regions. Granulation is a widespread processing technologies that has been successfully implemented in various industries to package loose solids and powders into a granular form, such as synthetic mineral fertilizers. This technology can be adopted in manure processing to facilitate export of manure nutrients in a marketable form. Furthermore, implementing this technology can facilitate the

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adjustment of manure nutrient ratios through the addition of necessary macro- or micronutrients to match market demands.

Implementing manure granulation as a nutrient export strategy requires a thorough understanding of the process technical and economic aspects to ensure viability and feasibility. To our knowledge, few studies have reported on granulation as a manure processing and nutrient export strategy (He et al., 2010; Mazeika et al., 2016; Sharara et al., 2016). We found no studies that evaluated the economic and technical prospects of this technology, particularly as a potentially collaborative technology for several livestock and poultry producers. Therefore, the goal of this study is to present a techno-economic optimization model that assesses manure granulation as a collaborative nutrient export strategy. We demonstrate the potentials of this processing technology through modeling manure granulation in two different case studies that represent two clusters of dairy producers in Wisconsin, USA.

2. Materials and methods

2.1. Experimental data

Dairy manure granulation was modeled using experimental data from multiple granulation tests on digested dairy manure sludge. The tests were carried out in a pilot plant at FEECO International, Inc. (Green Bay, Wisconsin, USA). The digested manure sludge was dewatered then naturally dried on concrete pads outdoor to increase the total solids content to approximately 35%. In the process model presented in this study, the pad drying step was eliminated and the total solids content was adjusted to 25%, a typical value for the solid-rich fraction after dewatering. Manure dewatering was modeled as mechanical screw press separation since it is a common technology in livestock manure processing that is relatively affordable. The fractionation of manure solids and nutrients (N, P, and K) between the solid-rich and liquid-rich fractions was modeled using literature values.

The granulation system components are shown in Fig. 1. The process relies on size agglomeration, drying, and screening to produce uniformly sized granules with a diameter of 2 to 4 mm that can be land applied using existing fertilizer applicators. Natural gas, electricity, and binder consumption, as well as dry matter loss on drying were estimated from the granulation tests and validated using literature on biomass processing and granulation.

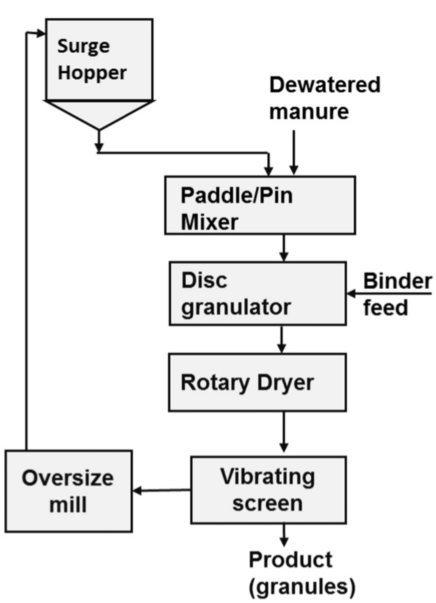

Fig. 1. Schematic diagram of manure granulation steps.

2.2. Techno-economic optimization model description

This techno-economic model was developed to assess the potential of granulation to assist in dairy manure management on individual and/or multiple dairy farms. The technical data collected from granulation test trials and literature surveys were complemented with economic data on the associated cost of purchase, installation, operation and maintenance of this system. The techno-economic model was formulated as an optimization problem that seeks to maximize the net present value (NPV) of the granulation facility investment. NPV analysis evaluates the profitability of a project by allocating all cash flows during the project life, i.e., capital investment, operating cost and revenue to a common basis of comparison, i.e., current dollar value (Alex Marvin et al., 2012). The capital investment (CAPEX) includes the purchase and installation of dewatering equipment as well as the granulation unit operations detailed in Fig. 1. The operating cost (OPEX) includes the cost of acquiring the manure from producers, estimated as the sum of N, P and K amounts in the manure valued at the market value of their synthetic counterparts. Other cost items in the operating cost include the cost of binder (lignosulfonate), energy, maintenance, labor compensation and the cost of transporting manure to the granulation facility and the transportation of manure liquid back to the original farm.

For a given sale price of granulated manure, the optimization model determines the ideal configuration for the granulation system if such a system can be achieved with positive NPV. The configuration of the system consists of the location of the granulation facility (or facilities) as well as which farms to supply that facility and whether that manure is dewatered on the originating farm or shipped for granulation as raw dairy manure. In this model, each farm was considered for participation in the granulation system as a potential manure source, host for the granulation facility, or both. All economic and technical parameters were allocated to a lactating cow basis to provide relevant data to dairy sector producers and investors. The mathematical equations comprising the optimization model as well as the nomenclature are included in the supplementary material.

For a given sale price of granulated manure, the optimization model determines the value of key logistic variables:

- The number of cows on each farm that participate in each granulation facility, whether as dewatered or as-excreted manure.
- The site(s) for the granulation facility (facilities).

2.3. Minimum sale price (MSP)

The price of granulated manure is a key parameter that drives this optimization model as it determines the project revenue. However, organic fertilizer markets vary in term of sale prices and the quality requirement for the fertilizer in terms of origin farm conditions and the stabilization process adopted, which makes it challenging to set a price point. Additionally, manure processing technologies, such as granulation, have been primarily considered to reduce nutrient concentration in a region. As such, it is often assessed economically in terms of the cost of implementation per unit output, rather than the sale price of the end-product. Accordingly, we modified the model by adding a search algorithm that iteratively feeds the optimization model with decreasing sale prices until the minimum sale price (MSP) is determined. The MSP corresponds to the commodity price that translates to a zero-profit (break-even) for the project (NPV = 0). The output of the model, therefore, becomes the optimal configuration of manure granulation that can be implemented at the lowest break-even price. That price is directly driven by the supply-side expenditure, i.e., production cost and discount factor and therefore provides important insights related to the impacts of project components, technology and inputs on the baseline for the product price.