The Nutrient Recycling Challenge

Background Information on
Nutrient Recovery Technologies and Pork and Dairy Production

This information is provided by EPA and Partners of the
Nutrient Recycling Challenge.

November, 2015

Nutrient Recycling Challenge

Background Information on Nutrient Recovery Technologies and Pork and Dairy Production

What type of innovation is desired and why?

Every year, livestock producers manage over a billion tons of animal manure which contains valuable nutrients (nitrogen (N) and phosphorus (P)) that plants need to grow. Livestock producers are looking for affordable technologies and approaches to manage and realize the full value of manure, as well as protect the environment. Manure can be a resource as a renewable fertilizer and soil amendment, but needs to be used properly to minimize water pollution and build healthy soils. Just like other fertilizer sources, as long as manure is applied to land from the right source, at the right rate and time, using the right methods, and in the right place, its nutrients can be recycled safely through agricultural systems.

However, because dairy and swine manure often contains significant water weight, it can be costly to transport and is commonly applied to land near where animals are raised. It can also be challenging for farmers to apply the precise levels of N or P that crops need by using raw manure, because the nutrient content of manure can vary, and N and P occur together in a fixed ratio. Use of the nutrients in this renewable resource could be better optimized (and potentially yield more economic value) if they could be more efficiently captured and easily transported to be reused.

One promising class of technologies is nutrient recovery technologies. Technologies that can recover the nutrients in manure present a tremendous opportunity—they concentrate N and P into products with potentially higher fertilizer and economic value than raw manure, and the environmental and economic benefits become substantial as more efficient methods to manage and transport nutrients are developed. However, these technologies are not yet economically feasible in all situations, and the markets for co-products they yield are immature or non-existent. More research and development is needed on technical and economic aspects of these technologies so that they can generate the specific products that the market is calling for. Producers would be incentivized to adopt nutrient recovery technologies if they could affordably convert manure into value-added products. Now is an optimal time to help cutting-edge innovations advance to the next level.

Overview of users of the technologies

Swine Production and Manure Management

As of 2012, there were 63,246 U.S. hog operations, with an average of 972 head per operation. Just under 70% percent of all hogs and pigs in the U.S. are raised on operations with 5,000 head or more (USDA, 2014). More information on U.S. pork companies is available here.

There are a number of different types of swine operations, including farrow-to-finish farms, farrow-to-nursery farms, farrow-to-wean farms, wean-to-finish farms, and finishing farms. There are three types of housing systems, including barns (confinement), hoop barns (usually for gestation and grow-to-finish pigs), and pastures (used for all stages of production). Each system has different production management needs, which are described in more detail here. Two primary manure management systems are described below. Generally, hog finishing manure contains approximately 50-35-25 pounds of N, P (P_2O_5), and K (as K_2O) respectively, per 1,000 gallons. More information on the nutrient content of swine manure is available in Table 2 here.

Deep Pit Finishing Systems: Such systems are most common in the Midwest. Deep pit finishing systems can be used on 1,000-5,000 head operations, and square footage varies accordingly. The typical operation size using deep pit systems is 2,000 head of swine, capable of generating 600,000 gallons of manure annually. The size of deep pits averages 80 ft. by 200 ft. by 8 ft. depth. The composition of typical pit manure is 40-30-30 N-P-K per

1,000 gallons, and 90-95% moisture content. Manure is generally stored for one year in pit and then pumped out, either prior to planting crops or after harvest.

Slurry Store or Anaerobic Lagoons Systems: Slurry store systems are similar to deep pit finishing systems from a building design standpoint, with the main difference being the use of external above-ground steel or fiberglass tanks, or, in-ground clay or concrete-lined holding structures that hold between 15-25 million gallons. Anaerobic lagoons are generally found on finishing farms averaging 5,000 pigs, or sow farms averaging 2,500 pigs. Manure is moved from shallow pits (generally under 24 inches) to lagoons on a daily or weekly basis using flush or shallow pit recycle systems. The depth of the tank or lagoon is determined by region and climate. Anaerobic activity in lagoons break down solids and leave much of the phosphorus at the bottom of the lagoons. Digestion rates will vary with climate and volatile solids loading rates. Sludge accumulates and may be stored in the lagoon for 20 years or more before being reclaimed. Water is irrigated out of the lagoon in spring, summer, and/or fall and applied to growing grain crops, hayfields, or pastureland. Annually, 4-7 million gallons may be irrigated out with a center pivot, traveling gun, or drag line hose. The volume irrigated out depends on rainfall and other weather conditions. Manure pumped from lagoons to spray fields is 99.5% moisture and 7-1-7 N-P-K per 1,000 gallons. The lagoon is never pumped out completely. A depth of 6-10 feet of liquid is maintained in the lagoon to maintain adequate biological activity. Some water may be recycled back into the pits to flush manure out of buildings. Recycling and flush systems dilute the nutrient value, energy value, and solids fraction of the material by as much as 80%. Such systems may be retrofitted with scrapers or other means of conveyance, thus increasing the nutrient and energy value and solids content.

Digesters on Swine Operations: Approximately 30 swine operations in the U.S. use anaerobic digesters to produce and capture methane (EPA, 2015). Digesters are often most economically and technically feasible for operations with at least 5,000 head. Anaerobic digestion converts N and P from their organic to inorganic species, which may increase opportunities for nutrient recovery, and also provides other inputs conducive to nutrient recovery, such as heat, electricity, and processing infrastructure (Yorgey et al., 2014).

Dairy Production and Manure Management Overview

The dairy industry is comprised of a mix of farms ranging from just a few cows to large operations that have several thousand cows. The average herd size on a dairy farm is 115 mature cows, though the majority (74%) of U.S. dairy farms have less than 100 cows. Over 50% of all milk cows are housed at operations with 500 head or more (USDA, 2014). More information on U.S. dairy cooperatives is available here.

Each day, dairy animals produce about 12 gallons of fresh manure (which includes feces and urine) per 1,000 lbs. average live weight. Fresh manure is comprised of approximately 86% moisture and 16% solids. One ton of fresh dairy manure solids contains approximately 10 lbs. of total N and 5 lbs. phosphate (P_2O_5). More information is available here.

Intensive production systems include tiestall barns, freestall barns, and open lots, which have different associated systems for managing manure. These manure management systems can include manual scrape systems, mechanical alley scrapers, flush systems, or collection in gutters and removal by a barn cleaner. Manure will often be kept in storage pits temporarily prior to application. Collection pits may also be used when solids are to be separated from the liquid portion of the manure. More details on these systems and processes may be found here.

Digesters on Dairies: Approximately 210 dairy operations in the U.S. use anaerobic digesters to produce and capture methane (EPA, 2015). Digesters are often most economically and technically feasible for operations with at least 500 head (EPA, 2011). Anaerobic digestion converts N and P from their organic form to inorganic forms. This process may increase opportunities for nutrient recovery, and also provides other inputs conducive to nutrient recovery, such as heat, electricity, and processing infrastructure (Yorgey et al., 2014).

Current state of the technology

In the past decade, innovators have developed and demonstrated technologies that can in fact recover a significant amount (> 95%) N and P from manure, and yield concentrated, dry, potentially valuable nutrient products. Such technologies are attractive to producers because they have the potential to:

- provide additional flexibility in manure management;
- yield nutrient products that are similar or identical to commercially available fertilizers;
- allow producers to economically transport manure nutrients greater distances by reducing the weight; and,
- lead to new revenue streams and/or decreased operational costs.
    - Freund’s Farm in Connecticut recycles the solids from anaerobically digested dairy manure and manufactures biodegradable planting pots that are sold nationally, increasing the overall profitability of the operation.
    - Jiang et al. 2014 showed that an integrated anaerobic digestion and ammonia stripping system at an 800 cow WA dairy could yield a net benefit from $9-38 a day, depending on the percentage of supernatant liquid recovered after solids removal and ammonia stripping efficiency (assumes that the price for <40% by weight, pH ¼ 2 ammonia sulfate slurry is the same as the price of commercial-grade dry ammonia sulfate).

A limited number of operations in the U.S. are experimenting with some type of nutrient recovery technology. Several factors contribute to a producer’s decision to adopt such systems, and can influence a technology’s prospects for long-term economic viability, including;

- a farm’s size and primary manure management system (e.g., flush or pit);
- options for handling the manure without such technologies, such as the amount of cropland available for direct application of the manure, or willingness of nearby farms to accept and use excess manure;
- ability to pay for new technologies and the staff/expertise to run and maintain them;
- the presence of other technologies, such as anaerobic digesters and solid-liquid separators, that are compatible with and can serve as a pre-stage to nutrient recovery; and
- the existence/maturity of reachable markets for the co-products or services the nutrient recovery technologies generate (e.g., fertilizers, nutrient credit generation).

Some examples of technically-viable nutrient recovery technologies and processes for dairy and swine manure include:

- precipitation and crystallization of struvite (magnesium-ammonium-phosphate);
- ammonia stripping and precipitation of ammonium sulfate;
- sequential screening, mechanical separation, precipitation of super-fine P solids using flocculants; and
- algal biomass-based systems

Table 1.0 – Sample Reference Papers on Nutrient Recovery Technologies

Technology/Process	Dairy References	Swine References
Precipitation and crystallization of struvite (magnesium-ammonium-phosphate)	Uludag-Demire et al. (2008), Zhang et al. (2010), Huchzermeier and Tao (2012)	Rahman et al. (2010) – *See Table 2 for lit. review*
Ammonia stripping and precipitation of ammonium sulfate	Jiang et al., (2014)	Zhang et al. (2012)
Sequential screening, mechanical separation, precipitation of super-fine P solids using chemicals	Ma et al., 2013	Vanotti et al. (2003), Szogi et al. (2015), p.52.
Algal biomass-based systems	Mulbry et al. (2008a)	Kebede-Westhead et al., 2006

See Table 2.0 for additional examples, including technical performance and costs where available.

In addition to these systems, some manure-to-energy technologies also concentrate nutrients in lightweight co-products. For example, dairy manure can be gasified to produce synthetic natural gas, and as a result of the process, the majority of P is concentrated in an ash co-product.

Despite the potential opportunities in nutrient recovery technologies, currently there are barriers to their being used more widely. First, such systems generally have high capital and/or operation and maintenance (O&M) costs. Generally, the greater the recovery efficiency, the greater the cost. For example, on a 500-head dairy installation, a primary and secondary screen-based system that recovers 15-25% of P and 15-30% of N may have capital and 20 years O&M costs totaling $66,000 - 78,000, while a struvite precipitation system that recovers 75% of P and 30% of N, and produces a high value fertilizer, has capital and 20 years O&M costs of over a million dollars (calculated from figures reported in Ma et al., 2013).

High costs can be especially prohibitive if lenders are unwilling to finance technologies without a proven track record of technical and economic performance. Despite documented successes in lab or pilot scale studies, there is little peer-reviewed technical and economic data available for commercial scale systems, and even less for systems that have been in prolonged commercial use. Furthermore, the available literature focuses more on anaerobically digested manure than raw manure. Generally, larger dairies (≥ 500 head) and larger swine operations (≥ 5000 head) are more likely to use digesters. Nutrient recovery technologies that work on larger operations with scale economies may not work on smaller operations.

Second, evidence shows that the markets for manure-based products are immature and these products struggle to compete pricewise with commercially available fertilizers on an elemental N and P basis. As a result, even well-functioning technologies may not generate a positive return on investment for producers because there are few steady markets for the nutrient products they generate within an economic distance. Market forces remain a primary barrier to scalability.

In addition to economic and market considerations, further research and development into novel, improved, or optimized technologies can advance the state of technology to meet producers' needs. Frontiers for innovation include:

- advanced solid-liquid separation
- phosphorus recovery
- nitrogen recovery/removal
- biochemical and bioplastics production and water reuse
- cost-effective technologies for smaller animal production operations

Table 2.0 - Examples of Nutrient Recovery Systems and Reported Technical/Economic Performance

System	Manure	P Recovery Performance	N Recovery Performance	Capital Costs	O&M Costs		Scale	Output(s)	Reference
Primary and secondary screening	Digested dairy manure	15-25%	15-30%	$32-36 per cow	$5-6 cow/yr		Commercial demonstration 12,500 cows	Fibrous and fine solids	Ma et al., 2013
Sequential screening + advanced non chemical	Digested dairy manure	50-65%	24-30%	$57-136 per cow	$25-50 cow/yr		Commercial Demonstration 3000 WCE*	Fibrous and very fine solids	Ma et al., 2013
Sequential screening + advanced chemical	Digested dairy manure and food wastes	75-90%	45-55%	$130-150 per cow	$25-75 cow/yr		Commercial Demonstration 6000 WCE	Fibrous and very fine solids	Ma et al., 2013
Struvite precipitation and crystallization	Digested or raw dairy manure	75%	30%	$100-150 per cow	$90-110 cow/yr		Commercial Demonstration 1400 WCE	Granular struvite fertilizer	Ma et al., 2013
Ammonia stripping	Digested egg layer manure	80-90%	55-65%	$400-500 per cow	$100-160 per cow		Full Commercial Operation 1.5 million layer	Ammonium sulfate solution	Ma et al., 2013
Ammonia stripping	Digested dairy manure	NR	Wide range; ≥ 90% NH_3 in optimal scenarios	$9-38 per day benefit if $ of output = commercial market $	$9-38 per day benefit if $ of output = commercial market $		Pilot-scale 800-cow volume	Ammonia sulfate slurry	Jiang et al., 2014
Centrifuge + polymerization + gasification	Digested dairy manure	90% (from advanced separation)	67% (from advanced separation)	$1,200-1,400 per cow	$60-80 cow/yr.		Pilot-scale 700 WCE	N&P-rich ash	Ma et al., 2013
Algal turf scrubber	Digested dairy manure	70-90% low loadings 50-80% high loadings	70-90% low loadings 50-80% high loadings	NR	A) $454-631 per cow-year		Pilot scale, various loadings	Dried algal slow-release fertilizer	Mulbry et al., 2008a
Algal turf scrubber	Raw swine manure	>90%	68-76%	NR	NR		Pilot scale, various loadings	Algal biomass	Kebede-Westhead et al., 2006
Struvite precipitation using chelating agent	Digested dairy manure	≈ 91%	NR	NR	NR		Pilot scale	Struvite granules	Zhang et al., 2010
Struvite precipitation with cone-shaped fluidized bed	Raw sine manure	Range of 0-80 % total P	NR	NR	NR		Lab and field scales	Struvite crystals	Bowers & Westerman, 2005

* Wet Cow Equivalent (WCE): A mature milking Holstein with a dry matter intake of 53 lbs. or more per day. Dry cows and heifers that are 18 months or older ≈ 0.5 WCEs each.

Table compiled by EPA, 2015.

References

Bowers, K.E. and Westerman, P.W. 2005. *Performance of Cone-Shaped Fluidized Bed Struvite Crystallizers* in Removing Phosphorus from Wastewater. American Society of Agricultural Engineers, 48(3), 1-8.

Chastain, John P. and Camberato, James J. *Dairy Manure Production and Nutrient Content*. Chapter 3a. Available at https://www.clemson.edu/extension/livestock/camm/camm_files/dairy/dch3a_04.pdf.

EExtension. 2015. *Managing Manure Fertilizers in Organic Systems*. Available at http://www.extension.org/pages/18628/managing-manure-fertilizers-in-organic-systems#.Vh7AwZjsncs.

Hoard's Dairyman. 2012. Available at http://www.hoards.com/sites/default/files/12_Oct10-top50-coops.pdf.

Huchzermeier, Matthew P. and Tao, Wendong. 2012. *Overcoming Challenges to Struvite Recovery from Anaerobically Digester Dairy Manure*. Water Environment Research, 84, 34-41.

Iowa State University Extension. 2007. B1-65, *Value of Manure Nutrients*. Available at https://www.extension.iastate.edu/agdm/livestock/html/b1-65.html.

Jiang, Anping, Zhang, Tianxi, Zhou, Quan-Bao, Li, Xiujin, Chen, Shulin, and Frear, Craig S. 2014. *Evaluation of an Integrated Ammonia Stripping, Recovery, and Biogas Scrubbing System for Use with Anaerobically Digested Dairy Manure*. Biosystems Engineering, 119, 117-126.

Kebede-Westhead, Elizabeth, Pizarro, Carolina, and Mulbry, Walter W. 2006. *Treatment of Swine Manure Effluent Using Freshwater Algae: Production, Nutrient Recovery, and Elemental Composition of Algal Biomass at Four Effluent Loading Rates*. Journal of Applied Phycology, 18, 41-46.

Ma, Jingwei, Kennedy, Nick, Yorgey, Georgine and Frear, Craig. 2013. *Review of Emerging Nutrient Recovery Technologies for Farm-Based Anaerobic Digesters and Other Renewable Energy Systems*. Prepared for the Innovation Center for U.S. Dairy. Available at http://csanr.wsu.edu/anaerobic-digestion/.

Mulbry, Walter, Kondrad, Shannon, Pizarro, Carolina, Kebede-Westhead, Elizabeth. 2008a. *Treatment of Dairy Manure Effluent Using Freshwater Algae: Algal Productivity and Recovery of Manure Nutrients Using Pilot-Scale Algal Turf Scrubbers*. Bioresource Technology, 99, 8137-8142.

Mulbry, Walter, Konrad, Shannon, and Buyer, Jeffrey. 2008b. *Treatment of Dairy and Swine Effluents Using Freshwater Algae: Fatty Acid Content and Composition of Algal Biomass at Different Manure Loading Rates*. Journal of Applied Phycology, 20, 1079-1085.

National Pork Board. 2014. *Pork Quick Facts 2014*. Available at http://www.pork.org/pork-quick-facts/.

Rahman, Md. Mukhlesur, Mohd. Salleh, Mohamad Amran, Rashid, Umer, Ahsan, Amimul, Hossain, Mohammad Mujaffar, and Ra, Chang Six. 2014. *Production of Slow Release Crystal Fertilizer from Wastewater through Struvite Crystallization- A Review*. Arabian Journal of Chemistry, 7, 139-155.

Successful Farming. *Top 25 U.S. Pork Powerhouses 2014*. Available at http://www.agriculture.com/uploads/assets/promo/external/pdf/pork_powerhouses_US_2014.pdf .

Szogi, Ariel A., Vanotti, Matias B., and Ro, Kyoung S. 2015. *Methods for Treatment of Animal Manures to Reduce Nutrient Pollution Prior to Soil Application*. Current Pollution Reports, 1, 47-56.

Uludag-Demirer, S., Demirer, G.N., and Chen, S. 2005. *Ammonia Removal from Anaerobically Digested Dairy Manure by Struvite Precipitation*. Process Biochemistry, 40, 3667-3674.

United States Department of Agriculture (USDA). 2014. *2012 Census of Agriculture; 2012 Census Full Report*. Available at http://www.agcensus.usda.gov/Publications/2012/#full_report.

United States Environmental Protection Agency (EPA). 2011. *Market Opportunities for STAR Biogas Recovery Systems at U.S. Livestock Facilities*. Available at http://www2.epa.gov/agstar/agstar-market-opportunities-report.

United States Environmental Protection Agency (EPA). 2015. *Livestock Anaerobic Digester Database*. Available at http://www2.epa.gov/agstar/livestock-anaerobic-digester-database.

Vanotti, M.B., Szogi, A.A., and Hunt, P.G. 2003. *Extraction of Soluble Phosphorus from Swine Wastewater*. Transactions of the ASAE, American Society of Agricultural Engineers ISSN 0001-2351, 1, 1665-1674.

Yorgey, Georgine, Frear, Craig, Kruger, Chad, and Zimmerman, Tara. 2014. *The Rationale for Recovery of Phosphorus and Nitrogen from Dairy Manure*. Washington State University. Extension Fact Sheet FS136E. Available at https://pubs.wsu.edu/ItemDetail.aspx?ProductID=15682.

Zhang, Lei, Lee, Yong-Lee, Jahng, Deokjin. 2012. *Ammonia Stripping for Enhanced Biomethanization of Piggery Wastewater*. Journal of Hazardous Materials, 199-200, 36-42.

Zhang, Tianxi, Bowers, Keith E., Harrison, Joseph H., and Chen, Shulin. 2010. *Releasing Phosphorus from Calcium for Struvite Fertilizer Production from Anaerobically Digested Dairy Effluent*. Water Environment Research, 82, 34-42.