Turning Manure Nutrients from a Liability to an Asset

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Introduction

With fertilizer costs still near record prices, dairy farms should expect to reap some reward for the nutrients contained in dairy manure. However, manure continues to be viewed at as a liability by most farms. Many farms continue to seek nutrient recovery systems that concentrate nutrients, produce low nutrient effluent and reduce manure odors during storage and application. Nutrient recovery technologies range from basic solid-liquid separation, systems targeting phosphorus or nitrogen or technology combinations that generate multiple fertilizers streams and potable quality water. As farms consider nutrient recovery technologies, they must weigh the current cost and benefits of their manure management practices and their management goals against the opportunities and drawbacks of innovative nutrient recovery systems.

Record Fertilizer Prices and Mounting Environmental Concerns

Even with fertilizer costs still near record levels, manure as a fertilizer source is often undervalued. Figure 1 shows the change in value of elemental nutrients since 2000.

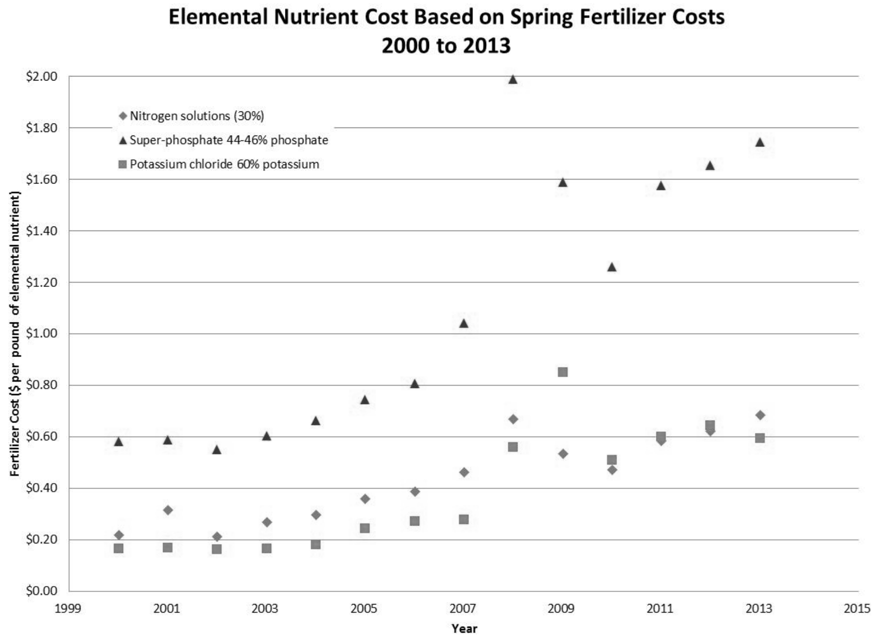

Figure 1: Elemental Nutrient Cost Based on Spring Fertilizer Prices 2000 to 2013 (USDA-NASS, 2014)

In the last 10 years, the cost of N-P-K fertilizers has increased on average 236%, compared to a very low and stable, prices from 1980 and 2004 (average increase of only 122%). The drastic increase in fertilizer cost has been driven by high oil prices and increasing demand caused by record corn and grain prices.

When viewed as a fertilizer, dairy manure provides a mix of nutrients and carbon necessary to maintain good soil health and high crop yields. Table 1 summarizes the annual production and nutrient content of manure from a single dairy cow.

Table 1: Annual Manure and Nutrient Production for a Lactating Dairy Cow (ASABE, 2005)

Manure Production			**Moisture Content**	**Nutrients**			**Solids**	
				N	**P**	**K**	**Total**	**Volatile**
ton/yr	*ft^3/yr*	*gal/yr*	*%*	*lb/yr*	*lb/yr*	*lb/yr*	*ton/yr*	*ton/yr*
27	876	6,552	87	361	62	84	4	3

Based on 2013 commercial fertilizer prices, the value of manure nutrients (N-P-K) for a single lactating cow is approximately $400 per year. This valuation does not include the value of carbon or micronutrients that are contained in the manure.

Manure as a fertilizer source, however, is often undervalued or not valued at all. As a commercial fertilizer replacement, manure is a challenge due to a number of factors including the dilute nature of nutrients, nutrient availability, and uneven nutrient distribution. Based on the ASABE (2005) dairy manure as excreted contains 55, 9, and 13 pounds of N-P-K per 1,000 gallons of manure, respectively. Factoring in dilution water added to manure, the N-P-K value drops to 33, 6, and 8 pounds per 1,000 gallons of manure. Due to the low nutrient content, manure applications rates of

5,000 to 12,000 gallons per acre are not uncommon to satisfy crop requirements. Because of a large portion of the manure nutrients are in the organic form, mineralization must occur before the nutrients become plant available. Organic nitrogen availability in the year manure is applied can range from 30% to 50%, due to decomposition of organic matter, year 2 nitrogen availability will be roughly 10 to 25% (Russelle et al., 2013 & Leikam & Lamond, 2003). Balancing the nitrogen availability with nitrogen credits from previous manure applications requires careful attention and planning to ensure that crop needs are met.

Other factors that contribute to the undervaluing of manure include the application cost, potential for soil compaction as well as social and environmental concerns such as runoff and odor. Nationally, manure application costs range from \$0.005 to \$0.031 per gallon of liquid manure applied (Gray et al., 2014). The wide range of application cost is influenced by application type (irrigation, dragline, injection, etc.), equipment used, fuel cost and distance from farm to field. Given the average cost of manure application at \$0.014 gallon (Gray et al., 2014), the annual cost to land apply as-excreted manure is just under \$90 per cow. Factoring in dilution water plus manure, the average annual application cost is closer to \$148 per cow. If proper application equipment and tillage practices are not employed, manure application can contribute to soil compaction. The density of manure as excreted is close to that of water (62 lb/ft^3). Adding bedding does change the manure density. Sawdust, shavings and straw will lower the density (to as low as 25 lb/ft^3) whereas sand bedding can cause manure density to increase to over 90 lb/ft^3. Considering the fact that a 7,500 gallon manure tank containing sand laden dairy manure can weigh 15 tons or more than the same tank hauling just dairy manure should provide some perspective on the importance of manure density.

Social and environmental concerns associated with land application of manure are well documented, ranging from runoff to surface waters contributing to eutrophication, algal blooms and fish kills, to high pathogen and nitrite/nitrate levels due to leaching to groundwater, to nuisance odors and road damage during transfer from the farm to the field. In August of 2014, the issue of agricultural nutrient management was again brought to the forefront of the national conversation due to a toxic, microcystis algal bloom in Lake Erie that contaminated the freshwater supply of Toledo, OH, causing 500,000 people to seek out alternative sources of freshwater (Henry, T., 2014). Lake Erie has suffered numerous algal outbreaks over the past decade with the largest recorded algal bloom occurring in 2011, covering more than 1,900 mi^2 according to the International Joint Commission (IJC) (2014). The commission noted that 44% of the total phosphorus entering Lake Erie is attributed to agricultural activities. The Ohio Environmental Protection Agency (OEPA) has looked closely at phosphorus sources in the Lake Erie basin and determined that agricultural phosphorus sources are either commercial fertilizer (84%) or manure application (16%) (OEPA, 2013). The OEPA study infers two key points; 1) livestock and dairy farms are doing a good job at minimizing the environmental impact of manure nutrients and 2) more emphasis needs to be place on utilizing manure nutrients in lieu of commercial fertilizers.

Recovering Nutrients

To address these issues with manure and to realize the market value of manure nutrients, many dairy farms are investigating nutrient recovery technologies (manure treatment systems). Nutrient recovery technologies can be broadly grouped into three categories including systems to address solid-liquid separation, phosphorus recovery and nitrogen removal (stripping). In most cases, nutrient recovery systems will employ combinations of technologies to address the farm specific manure management concerns.

Solid-Liquid Separation. Solid-liquid separation, in this context, is the physical process by which solids are separated from liquid manure (water). For dairy manure, solid-liquid separation is commonly achieved by mechanical separation; however sedimentation can be successfully managed under certain conditions.

Sedimentation. Sedimentation or natural settling occurs due to density differences between manure particles and water. Denser (heavier) particles will tend to drop out of suspension provided the material is diluted and agitated before entering the settling basin. Without dilution and agitation, very little separation will occur. Most dairy farms will observe sedimentation in long term manure storages. The challenge with sedimentation is that separation of solids and nutrients is highly dependent on environmental conditions, requires significant time (months) for fine solids and is difficult to predict. In addition, the settled sludge is generally loose and easily resuspended with minor agitation or pumping. To overcome these challenges, farms that have successfully used sedimentation for nutrient recovery, typically construct multiple manure storages in series with gravity overflow to ensure a long retention time and minimal disturbance. It has been reported that sedimentation is capable of removing 50% of all solids and effective for fine solids (NCSU).

Mechanical Separation. Mechanical solid-liquid separation systems are commonly used by dairy farms to reduce issues with pipe clogging, sludge accumulation in storages and crust formation. Separation of solids is reported to also reduce odor potential during liquid manure storage. Liquid with coarse solids removed is generally easier to land apply, requiring less agitation and a reduced likelihood of clogging equipment. Common mechanical separators include stationary screens, screw press separators, rotary drum thickeners, centrifuges and hydrocyclones. Separation efficiency is influenced by manure type, screen size, flow rate, and the solids concentration liquid.

Most mechanical separators rely on particle size and shape as the basis for separation. Mechanical separators can be effective down to particle diameters of 1 micron, however most system target slightly larger sizes. Centrifuge separators rely on density differences between the solid and liquid fractions, in addition to particle size. Belt press thickeners and dissolved air flotation (DAF) are mechanical system capable of removing finer particle sizes, but they rely on chemical treatment of manure to be effective.

Solid separator technologies vary widely in separation efficiency and the characteristics of the fiber removed. Basic mechanical separator, the static screen, can achieve solid separation efficiencies in the range of 10 to 25% with the moisture content of the solids removed in the range of 80 to 90%. Screw press separators on the other hand provide more process control and can achieve separation efficiencies in the range of 25 to 40%, with the moisture content of the solids typically less than 75%. Using multiple separators in series with decrease screen pore size can result in solids removal rates as high as 50%. Even good solids removal, solid-liquid separation as a nutrient recovery technology is relatively ineffective achieving roughly 10-20% reduction of nitrogen and a 5 to 20% reduction of phosphorus contained in the liquid filtrate (Frear & Dvorak, 2012). Most of the nutrient removal will be in the organic form, tied to the manure fibers, while fine particulate and dissolved solids remains in the liquid.

Ultrafiltration. Ultrafiltration (UF) is a form of solid-liquid separation, but due to the unique nature of this technology it requires special consideration. The basis for UF is the application of high pressure on one side of a membrane to create a pressure gradient across the membrane. The pressure gradient tends to drive water and dissolved solids through the membrane pores to the low pressure side of the membrane. Normal operating pressures for UF are in the range of 50 to 150 psi. Permeate is the mix of water and low-molecular weight dissolved solids which passes out of the membrane. The mix of solids and water remaining inside the membrane is termed retentate. Ultrafiltration is most effective at removing solids (solutes) with molecular weights greater than 1,000 or particle sizes greater than 0.01 micron. For nutrient recovery, UF is commonly used to concentrated fine particulate, dissolved solids and phosphorus in the retentate. Ultrafiltration is also effective at removing bacteria, protozoa and some viruses from the liquid. Membrane technologies like UF are often capital intensive to install and have relatively high operating costs due to energy required to achieve the input pressures of the UF. Operation of a membrane system does also require a trained operator and regular monitoring to ensure proper operation.

Reverse Osmosis. Osmosis is the natural process by which water (the solvent) migrates across a semipermeable membrane to equalize solute concentrations differences on each side of the membrane. Typically the solvent migration is in the direction of the high solute concentration. In reverse osmosis (RO), high pressure is applied to the high solute concentration side of the membrane to force the solvent flow in the direction of the low solute concentration, hence reversing the natural tendency. Similar to UF, RO can occur over a wide range of pressures (30 to 1,200 psi) depending on solute makeup and concentration. Reverse osmosis is capable of retain virtually all particles, germs and organics remaining in the liquid, resulting in an effluent that is essentially pure water. Reverse osmosis is commonly used to desalinate sea water to produce drinking water.

From a nutrient recovery standpoint, RO is typically used as the polishing step. Potassium is the key fertilizer component recovered using RO. For RO to be effective, the input liquid needs to be free of all particulate. Pretreatment including solid-liquid separation, phosphorus removal and ammonia removal should precede RO. Similar to UF, the key challenge with RO is maintaining clean, consistent input to minimize fouling or clogging of the membrane. Reverse osmosis systems are generally capital intensive and require significant power to maintain the high operating pressure of the system.

Phosphorus Recovery

Two phosphorus nutrient recovery technologies that have been explored and applied at commercial scale in the United States are chemical phosphorus removal and struvite production.

Chemical Phosphorus Removal. Chemical phosphorus removal by coagulation and flocculation of phosphorus using metal salts and polymers has been successfully used to achieve phosphorus reduction of 80% or more in liquid dairy manure. Phosphorus in manure is generally dissolved or in a colloidal form, making it difficult to separate using physical means. Coagulation, the process of thickening the colloidal phosphorus, is initiated by the addition of lime or a metal salt, typically iron or aluminum. Coagulation works by charge neutralization, phosphate carries a negative charge while the salts (coagulants) carry positive charges, thus causing an attraction and creating a larger, denser molecules (O'Melia, 1970). Once the phosphorus is coagulated, a polymer is added to the manure to bind together coagulated molecules into a larger particle.

Figure 2: Belt Press Separator Outlet and Press "Cake"

Flocculated particles are rather easy to separate using a using a belt press separator and dissolved air flotation (DAF). Belt presses use a combination of gravity thickening, porous belts and pressure to dewater the flocculated material. The resulting solid material, "cake", contains the separated phosphorus and solids. Typically, the solid content of the cake is in the range of 25 to 35% and can be land applied as a solid or composted. Dissolved air flotation works by releasing small air bubbles into the bottom of a flotation tank. As the bubbles rise through the water column, they adhere to suspended solids, causing the solids to float to the surface where they are removed by a skimmer. Dense solids will settle to the bottom of the flotation tank and are removed as a sludge material. The skimmed solids and sludge can be mechanical dewatered to produce a stackable manure solid similar to the belt press cake. Liquid effluent from chemical separation is typically less than 1% solids, contains low levels of phosphorus, has minimal odor and is high in ammonia and potassium.

While chemical separation is very effective at recovering phosphorus and commercially available, the equipment, chemicals and labor are costly. Also, the chemical balance of the system is sensitive to small changes in pH, temperature and manure characteristics (lactating versus dry cow manure) resulting in continual monitoring to maintain efficient performance. Farms using chemical phosphorus removal have benefitted installing anaerobic digesters prior phosphorus removal system. In addition to providing a homogenous and warm input to the phosphorus removal system, digestion also increases the mineralized phosphorus level through the breakdown of organic material.

Struvite Production. Struvite is a white to brownish-white, crystalline solid containing equal molar parts magnesium, ammonium and phosphate (chemical formula $NH_4M_gPO_4 \cdot 6H_2O$). Analysis of the pure form of struvite provides an N-P-K formulation of 6-29-0 (Hotaling & Hamkins, 2006). Natural formation of struvite requires high concentrations of the soluble forms of magnesium, nitrogen and phosphorus, alkaline or increasing pH levels, and temperatures in the range of 60 to 95^{o}F (Hanhoun et al., 2011). High turbulence areas, such as pipe elbows or pumps, are common locations where formations begin. In the municipal wastewater treatment industry, struvite formation has long been a problem, causing restrictions on pipe flow to complete clogging of pipes, pumps and other process equipment. The nutrient balance of struvite as well as its granular nature makes it an appealing nutrient recovery technology for dairy manure.

Figure 3: Struvite Crystals (Dangaran)

Commercial struvite reactors are typically designed as fluidized beds using fine particles to "seed" the crystal formation. Magnesium salts are generally added to the manure as it flows into the reactor to ensure adequate levels for struvite formation. Mixing is achieved by the addition of air in the bottom of the reactor or by the turbulence caused by the fluidized bed. Denser crystals (seed material coated with struvite) tend to settle to the bottom of the reactor and are periodically funneled out through a cone bottom. Struvite crystals drain of moisture easily, creating a dry, solid granular fertilizer. Effluent from the reactor typically flows out the top of the system.

Struvite production is not without challenges. Production from dairy manure is pretreatment intensive, requiring solid-liquid separation, denitrification and potentially anaerobic digestion, to maintain stable struvite production. Highlighting the importance of pretreatment, research has indicated that total suspended solids levels exceeding 0.1% adversely impact precipitation of struvite (Hotaling & Hamkins, 2006). Elevated calcium levels in the manure may also interfere with struvite production and resulting in the formation of calcium phosphate minerals. Similar to chemical phosphorus removal, struvite production does require a steady input of materials to balance the system chemistry and maintain separation efficiency.

Nitrogen using Ammonia Stripping

Ammonia stripping is simple chemical process that allows ammonia to be removed from liquid manure and converted to a marketable fertilizer. The stripping process has been developed and used in the wastewater industry for years as a means for cost effectively lowering the ammonia levels of wastewater (USEPA, 2000).   According to the EPA (US2000), stripping is best suited for fluids containing 10 to 100 ppm of ammonia.

In order to strip ammonia from manure, the pH of the liquid must first be adjusted to a range of 10.8 to 11.5 using lime or caustic. The pH adjustment is necessary to convert ammonium to ammonia. Depending on the level of pH adjustment, the temperature of the manure should be in the range of 68 to 120^{o}F (higher temper for lower pH). Using a countercurrent system shown in Figure 4, after pH adjustment, the liquid is introduced into the top of a packed bed tower. The packing material helps to distribute the downward flow of water. Ambient air is drawn into the bottom of the tower, creating the countercurrent flow of liquid moving downward from the top while air is moving upward from the bottom. Free ammonia is stripped from the falling water droplets and carried out of the tower with the air. To create a marketable fertilizer, the exhaust air from the stripper is directed into an absorber (another packed bed tower) where sulfuric acid used to condense the ammonia into ammonium sulfate. The exhaust from the absorber can than become the inlet air to the stripper, creating a closed loop system. Ammonia free water is discharged from the bottom of the tower.

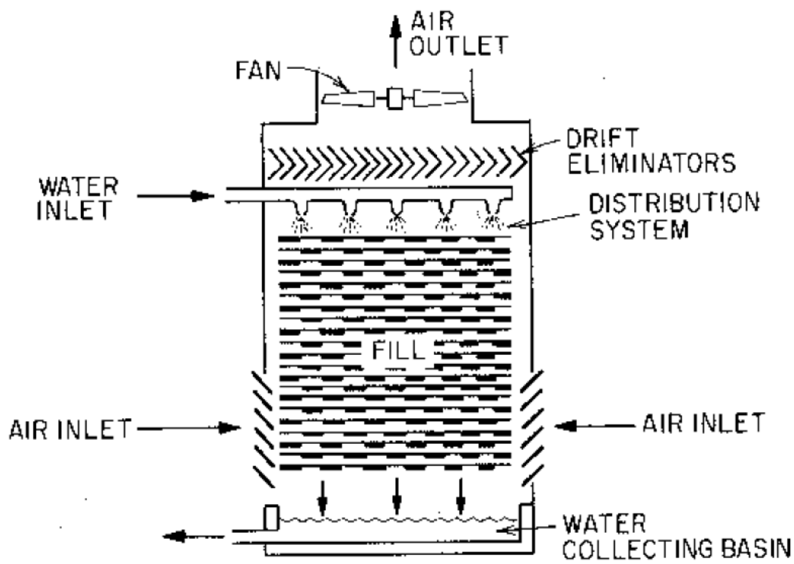

Figure 4: Countercurrent Ammonia Stripper (USEPA, 2000)

To avoid fouling of the stripper, pretreatment is necessary. In most commercial applications coarse solid-liquid separation is used as well as ultrafiltration or a similar fine solid removal system to create a relatively clean input. Without proper solids removal, clogging of the filter media is a major concern.

Complete Nutrient Recovery Systems

Combining various nutrient recovery technologies to achieve a desired outcome, concentrated phosphorus solids or discharge quality water for examples, has gained momentum over the past several years. With a complete system, manure is typically broken down into several nutrient rich fractions including; a concentrated organic solids containing phosphorus and organic nitrogen, ammonium sulfate, a potassium concentrate, and clean water. The exact nutrient fractions and composition will depend on the technologies implemented, site specific conditions, and the management goals. Depending on the goals, systems can be tailored to remove only solids, to remove solids and some phosphorus (20% to 99%), to remove solids, phosphorus and nitrogen or to remove all water contaminants. Creating a system tailored to the farm needs and management goals allows a producer to a treatment train that addresses the agronomic balance between manure nutrient and crop needs, while minimizing the capital and operational costs. The benefits complete nutrient removal are that clean water that can be used as irrigation with minimal oversight and no odor and concentrated nutrient sources that can be used in a manner similar to commercial fertilizers.

Nonetheless, the decision to installing a complete nutrient recovery system does require careful consideration to ensure that the correct technologies is implemented and that the system is financial viable. To start, the farm management should closely evaluate the current and future needs and costs of nutrient management including manure application and regulatory compliance to determine the exact nutrient recovery needs. During this evaluation, a reasonable unit treatment cost can also be determined based on current practices, necessary site modifications, and future fertilizer values. As discussed earlier, the capital cost of such systems is generally very high with equally challenging operational costs due to the labor, energy and chemical requirements. Successful operation of a system requires well trained operators. To maximize the value, nutrient removal products should be storage and managed separately. However, conventional manure storage designs may not meet the storage requirements for some fertilizer products. A plan on how to market the "new" fertilizers should also be developed. Questions should be asked to assess if a market exists? And how would potential users value the manure based nutrients compared to commercial fertilizers? In addition, dairy farms should consult local permitting authorities to determine how the installation and operation of a nutrient recovery system impacts environmental permits.

With proper planning, these traditional and innovative nutrient recovery systems can successful be integrated in to the farm, reducing environmental concerns and helping the farm to realize the true economic value of manure.

Conclusions

The nutrient value of dairy manure is real and has measurable value. However, minimizing the negative attributes of manure and the stigma that it is not a valuable fertilizer is still a challenge. Nutrient recovery offers the opportunity to partition nutrients into concentrated products, while reducing odor potential and producing clean water for irrigation or discharge. Adopting individual nutrient recovery technologies like solid-liquid separation or chemical phosphorus removal allow the producer to address manure application or agronomic issues relatively easily and potentially cost effectively. If the goal is to maximize the value of nutrients or to reduce the volume of liquid manure applied to fields, the farm may need to look to a complete nutrient removal system capable of producing clean water. Due to the potential for high capital and operation costs, farms must be diligent in their assessment of technologies and review of pro forma financial models carefully. Complete nutrient removal systems provide an opportunity to create real value from manure and address environmental and social concerns by creating stable, easily managed renewable fertilizers.

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