



NUTRIENT RECOVERY: PRODUCTS FROM DAIRY MANURE TO IMPROVE SOIL FERTILITY

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Dairy Manure Management—Issues and Potential Solutions

Dairies are in the business of producing milk. Dairy herds also produce manure, and managing this byproduct—and the nutrients it carries—can be a significant challenge for some dairies. Meanwhile, crop farmers, sometimes in areas close to dairies, generally use commercial, inorganic fertilizers to provide nutrients to their crops. Due in part to intensive cultivation with little input of organic matter, many of these same crop farmers face soil health challenges related to decreases in organic matter content and loss of soil through erosion. Previous research has found that manure application can reduce soil erosion at multiple sites across the United States (including Moscow, Idaho [Gilley and Risse 2000]), and that manure-derived organic amendments reduced soil-borne pathogens in red raspberry fields in British Columbia (Forge and Kempler 2009). Manure and its nutrients can be a valuable source of organic matter as well as nitrogen, phosphorus, and other nutrients for soils and crops. Such uses could help solve manure management challenges for dairies while helping to address soil health issues and meeting—partially or fully—the nutrient demand of crops. Recovering and using nutrients from manure also recycles those nutrients, and can therefore address some of the longer-term societal challenges to inorganic fertilizer use: the limited supply of mined nutrients such as phosphorus and the high-energy consumption of producing synthetic nitrogen.

However, there are complex trade-offs involved in this potentially win-win scenario. On the dairy side, transporting raw manure significant distances is expensive. Yet, applying manure at higher than agronomic rates to nearby fields (which reduces the transport costs) can contribute to air and water quality concerns, including:

- Eutrophication,
- Nitrogen pollution of water,
- Ammonia volatilization, and
- Greenhouse gas emissions, contributing to climate change.

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Anaerobic digestion (AD) has been used on some dairies to treat manure, and the technology can reduce greenhouse gas emissions, while producing renewable energy and addressing other issues such as odor and pathogen loads in manure (US-EPA 2004; US-EPA 2005; Martin and Roos 2007; US-EPA 2008). However, traditional AD does not alter the nutrient content of manure, and may even exacerbate nutrient over-application concerns when nutrient-rich organics are imported for co-digestion (Camarillo et al. 2013). In most cases, dairy AD operations in the Northwest do carry out co-digestion, accepting food waste as an additional feedstock. This improves the methane production and the economics of AD (especially if they receive tipping fees) (Kennedy et al. 2015), but could heighten the need for dairies to manage nutrients at the whole-farm level (Harrison et al. 2007).

Technologies that recover nutrients—particularly nitrogen and phosphorus—from manure or from AD effluent (Figure 1) have the potential to help some dairies avoid over-application of nutrients to fields during manure management, reducing water quality concerns. They also have the potential to provide a local nutrient source for nearby crops, and some products also add organic material to the soil, contributing to improved soil health. Nutrient

recovery and associated post-processing can lead to saleable products that, as the nutrients are more concentrated, can be transported greater distances more cost-effectively than manure. They can also be applied to fields in a targeted and controlled manner. When used in combination with anaerobic digestion, nutrient recovery can also complement AD technologies, providing value-added products and improving the economics of the overall manure management operation. Through re-distribution of the recovered nutrients to areas of high demand (e.g., horticultural crops), such technologies could contribute to nutrient supply better matching demand across a watershed. The logic for nutrient recovery is covered in more detail in [The Rationale for Recovery of Phosphorus and Nitrogen from Dairy Manure](#) (Yorgey et al. 2014).

The purpose of this publication is to increase awareness of nutrient recovery products in the early stages of commercialization. We aim to provide a summary of the status of nutrient recovery products’ research and application in the northwestern U.S. to help interested dairy producers and growers, agricultural professionals, regulators and others gain an understanding of the state of knowledge related to these products.

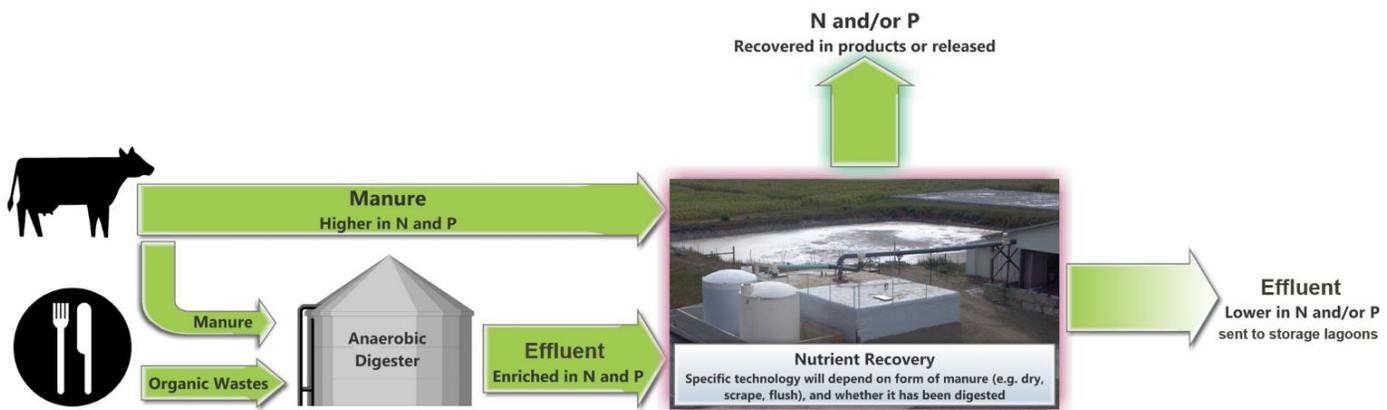


Figure 1. A generalized schematic of the phosphorus and nitrogen nutrient recovery process. Raw manure can be processed directly using different nutrient recovery technologies (upper arrow). It can also be processed first through an anaerobic digester, with or without the addition of other organic materials (lower arrows), before beginning the nutrient recovery process. The remaining liquid effluent is stored in lagoons. Modified from the image created by Nicholas Kennedy and published in Yorgey et al. (2014).

Nutrient Recovery Technologies

Numerous nutrient recovery technologies were in development or in the early stages of commercialization as of early 2018. Most of these processes recover, concentrate, and partition nutrients into diverse products, with the effluent—the remaining liquid—then being stored in lagoons until it is transported to fields. Some nutrient recovery technologies simply separate out different solid fractions, which are naturally rich in particular nutrients. Other technologies use chemical or biological processes to capture specific nutrients. These technologies are generally applied in three main sequential steps (Figure 2) with cost and complexity increasing as additional steps are added:

- *Solids separation*: physical separation of fibrous solids (separated fiber) with low

nutrient content. The remaining effluent is nutrient-rich but easier to manage and process with additional technologies.

- *Advanced solids separation*: extraction of finer solids rich in phosphorus using technologies such as centrifuge or dissolved air flotation (DAF) systems. Cleaner effluent remains.
- *Advanced nutrient recovery*: different technologies, such as struvite crystallization and ammonia stripping, produce a variety of phosphorus- and nitrogen-rich products. The resultant effluent has a vastly reduced nutrient content, though it still has some remaining N, P, and salts.

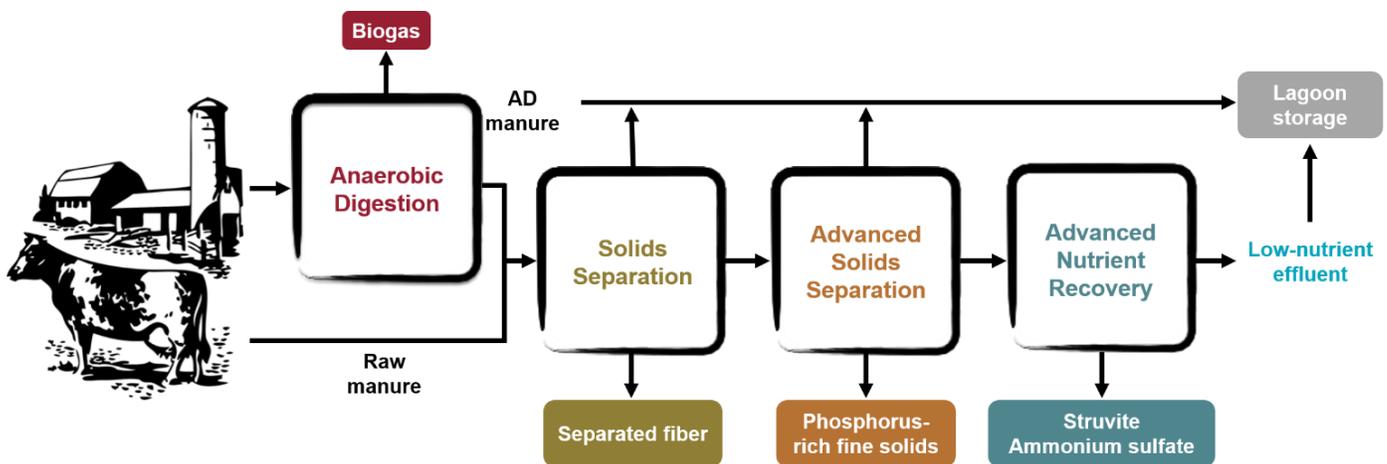


Figure 2. A generalized schematic showing the three main sequential steps where nutrient recovery technologies are applied, the products that can be obtained from these technologies, and the remaining liquid effluent, which can be further treated or stored in lagoons. Figure created by Timothy Ewing, and modified with permission.

Due to the reduction in nutrient content, dairy producers could apply the effluent to crops at higher application rates. However, the resulting change in nutrient ratios (i.e., proportion of available nitrogen, phosphorus, and potassium [N-P-K]) needs to be appropriately managed. That is, the effluent needs to be analyzed to determine the macronutrient that limits the amount that can be land applied, and what is, therefore, the maximum application rate. For example, if most of the N and P have been removed, the application rate may be determined by the maximum amount of K that can be applied.

Though cost and technological challenges currently limit their use on U.S. dairy farms, additional technologies exist to further process the resulting liquid effluent, with the potential to produce water that is clean enough to be used for purposes such as animal drinking water or for dilution purposes.

Established and emerging technologies to recover nutrients from manure are described in [Approaches to Nutrient Recovery from Dairy Manure](#) (Frear et al. 2018). As a companion publication, this publication focuses on the products developed

through these nutrient recovery technologies, describing their characteristics and their basic composition, and reviewing available information on their nutrient availability, effects on plant growth and crop yield, and potential for environmental impacts. All these technologies can help achieve nutrient balance at the farm scale (Harrison et al. 2007), providing tools for avoiding environmental impacts from excess nutrients. As with any nutrient management strategy, however, the management of these products—the type of application, timing of application, and rate of application, for example—will determine the risk of environmental impacts, and must therefore be appropriately managed.

As many of these nutrient recovery products are in the development or early commercialization stage, not enough published information exists for a comprehensive review or for the development of specific recommendations for their use. Our intent is therefore to summarize in one publication the information that is currently available on the following nutrient recovery products: separated solids, phosphorus-rich fine solids, struvite, and ammonium sulfate. Raw manure and AD manure are also described simply to provide a point of comparison for the other, less common, nutrient recovery products.

Manure—A Useful Point of Comparison

Raw Manure

Raw manure (Figure 3) can be defined as manure that has not gone through any managed treatment (such as anaerobic digestion, composting, heat treatment) nor been left to age naturally for any significant period. To distinguish it from the anaerobically digested (AD) manure, also discussed in this section, we use a commonly applied alternative to raw manure: non-AD manure.

Raw manure can be collected at any point in a manure handling system and from operations using different manure handling systems, so will therefore differ in its content of N, P, K, and solids. Another major factor affecting the composition of raw manure is the type of bedding used in the animal housing area.

Product Composition and Nutrient Availability:

The composition of raw manure is variable. Scraped manure will have a higher solids content and greater nutrient content in comparison to manure that has been removed with flushing (for example, 25 percent solids for scraped versus 8 percent for flushed manure; 6 lb of N per U.S. ton of slurry [wet base] versus 10.6 lb of N per U.S. ton for scraped manure; both sources have typical contents of 2.6 lb of P per U.S. ton, and 8 lb of K per U.S. ton [ASABE 2005]).

Typical nutrient content values of dairy manure handled different ways (Table 1 and Table 2) can be used as rough estimates of nutrient content to expect in manure. Because manure nutrient content varies widely among farms, and even over time on the same farm, we recommend manure testing to get accurate values for a particular farm. Soil tests are the best indicators of the long-term effects of manure application on soil fertility. Producers commonly test for nitrate-N every fall; they should also plan to test for P and K every two to three years.



Figure 3. Raw manure scraped from the barn floor. Photo: Reimphoto, with permission.

Table 1. Typical nitrogen (N) concentrations for different handling systems (Bary and Harrison 2017).

Manure Type	Typical Total Nitrogen	First Year Fertilizer Value (% of Total N)
Dry stack (35% solids)	7–11 lb/wet ton	20–50%
Separated solids (20% solids)	3–7 lb/wet ton	0–20%
Holding tank (scraped, 8% solids)	18–24 lb/1000 gal	30–60%
Lagoon, no agitation (<1% solids)	2–6 lb/1000 gal	60–90%
Lagoon, agitated (2–6% solids)	6–18 lb/1000 gal	30–60%

Note that most of the manure nitrogen that is not available to plants in the first year (First Year Fertilizer Value) is stored in soil organic matter. It is then slowly converted to plant-available forms in later years. Over a 5-year period, 60–90% of the manure N applied becomes plant available (Bary and Harrison 2017).

Table 2. Typical phosphorus (P) and potassium (K) concentrations for different handling systems (Bary and Harrison 2017).

Manure Type	Typical Phosphorus	Typical Potassium
Dry stack (35% solids)	3–5 lb/wet ton	10–20 lb/wet ton
Separated solids (20% solids)	0.7–1.3 lb/wet ton	1–3 lb/wet ton
Holding tank (scraped, 8% solids)	5–7 lb/1000 gal	15–25 lb/1000 gal
Lagoon, no agitation (<1% solids)	<0.5 lb/1000 gal	2–8 lb/1000 gal
Lagoon, agitated (2–6% solids)	1–5 lb/1000 gal	10–20 lb/1000 gal

Note that to convert P to the same units used in marketing fertilizers (P_2O_5), the typical phosphorus values need to be multiplied by 2.29. Not all of the P in manure is immediately plant available. To convert K to fertilizer units (K_2O), the typical potassium values need to be multiplied by 1.20. Most of the K in manure is immediately plant available (Bary and Harrison 2017).

Effects on Plant Growth and Yield: Dairy manure can be a good source of nutrients for crop growth. It not only provides macronutrients like N, P, and K, but also provides many micronutrients as well as promoting good soil health through impacts on the physical and biological properties of soil. For example, a three-year study demonstrated that non-AD manure could provide an effective source of nitrogen to pasture (Saunders et al. 2012). Several existing publications are available through University Extension publications that outline manure use in other crops (Sullivan and Cogger 2012; Sullivan 2015; Bary et al. 2016; Bary and Harrison 2017; Downing et al. 2017).

Food safety issues can be a concern with manure as manure may carry pathogens that affect humans and that can be transferred to the food crop. Composting or anaerobic digestion can reduce (though do not, necessarily, eliminate) these concerns. The US Environmental Protection Agency (EPA) has developed standards for treating biosolids. Processes that meet those standards can be considered “processes for reduction of pathogens” (PFRPs), allowing biosolids to be applied to the soil (US-EPA 1994). These standards are also applied to manure. For example, the Oregon Department of Environmental Quality adopted these requirements for commercial composting facilities (Brewer et al. 2017). The USDA National Organic Program

standards already require a 120-day interval between the application of raw manure for crops in contact with the soil and 90 days for crops such as small grains that do not come in contact with the soil (CFR 2002). As of late 2016, the Food and Drug Administration was assessing these risks for

fruits and vegetables normally eaten raw, and reviewing extensive research on the number of days needed between applications of raw manure as a soil amendment and harvesting, to minimize the risk of contamination (US-FDA 2016; US-FDA 2017).

Anaerobically Digested (AD) Manure

AD manure (Figure 4) is the output once raw manure has been processed through an anaerobic digester where microbial activity leads to the production of biogas. The resulting AD manure will have more ammonia-N and inorganic P than non-AD manure (even without inputs from co-digested organics), due to the action of the microbes on organic forms of these nutrients in the digester. Other fractions of AD manure will remain similar to non-AD manure. In practice, most dairies that have anaerobic digesters will also carry out some sort of liquid-solid separation before storing the liquid effluent in lagoons (see *Separated Solids*, below).



Figure 4. Storage lagoon for AD effluent. Photo: Jim Jensen, WSU

Product Composition: Concentrations of ammonia-N and ortho-P in AD manure can be 20–40 percent higher (or more) than in non-AD manure (Ma et al. 2017), due to the action of bacteria on organic N and organic P. This increase in nutrient

concentration, once large portions of the organic carbon has been transformed into biogas, occurs whether the influx to the anaerobic digester is only manure or manure mixed with other feedstocks, and whether the AD manure has gone through liquid-solid separation or not.

Nutrient Availability: Since more of the N in AD manure is in the form of ammonia, when compared to non-AD manure, more can be lost during lagoon storage and possibly at the time of land application. Anaerobically digested manure that has subsequently had the large particle solids removed through fiber separation can infiltrate into the soil more easily at the time of land application, and therefore conserve ammonia-N. Ammonia-N is directly available for plant uptake. These differences in the form of N found in manure and AD manure, therefore, could lead to different availability to plants, even if both products are applied at the same rate (though see conclusions from Saunders et al. 2012, below).

Effects on Plant Growth and Yield: Anaerobically digested dairy manure can be a good source of nutrients for crop growth. It not only provides macronutrients like N, P, and K, but also provides many micronutrients, and promotes good soil health through impacts on the physical and biological properties of soil. Though the form of N may differ, a three-year study demonstrated that AD manure applied to grass harvested for silage, at the field scale, provided similar amounts of available N as non-AD manure, when applied at equal rates of total N (Saunders et al. 2012).

Nutrient Recovery Products—Description and Effects on Crops and Soils

Separated Solids

Separated solids (Figure 5) are obtained when the coarser solid fractions in AD or non-AD manure are physically removed. Such separation can be achieved by a variety of gravity and mechanical methods. The primary reason to remove large particle solids is to avoid their deposition in storage lagoons. In addition, separating large particle solids can also partition a small portion of nutrients that can be more easily transported longer distances or exported off-farm. Some dairy farmers choose to recycle the solids as a livestock bedding source.



Figure 5. Piles of separated fiber after processing through an anaerobic digester. Photo: Sonia A. Hall, WSU.

Phosphorus-Rich Fine Solids

Very fine, clay-like solids that are in suspension in the liquid effluent are obtained after primary solids separation (Figure 6).

Phosphorus is preferentially associated with these suspended solids, so their removal produces a phosphorus-rich product. Centrifuges are one method currently used.

Product Composition: Typical nutrient content of separated solids are summarized in Table 1 and Table 2, above (see values under *Separated solids*).

Nutrient Availability: The nutrient availability of separated solids is highly dependent on the breakdown of organic nitrogen by soil microbes. A good method for determining the availability of organic-N in manure solids is outlined in [Estimating Plant-Available Nitrogen from Manure](#) (Sullivan 2015). Most of the K is plant available, though not all of the P (Bary and Harrison 2017).

Effects on Plant Growth and Yield: The effects of separated solids on plant growth and yield are not yet well understood. Greenhouse studies using separated solids to replace peat moss as a plant growth medium substrate found that, with post-AD treatments to adjust pH, the amended dairy fiber can produce a substrate equal to peat moss (MacConnell and Collins 2007), suggesting it may be worth evaluating its effect on plant growth and yield in field settings.

Dissolved Air Flotation (DAF) systems can also be used and remove fine solids as they coalesce with added polymers (sometimes in combination with flocculants or binders) to produce larger particles that settle out (see details of the process in Jiang et al. 2013). These solids are recovered in wet form, and additional dewatering is needed to produce a marketable, value-added product.



Figure 6. P-rich solids from processed dairy manure. Photo: Regenix, with permission.

Product Composition: Collins et al. (2016) found that phosphorus-rich DAF solids are characterized as 2-3-1 (N-P-K). Additionally, they characterized their elemental composition, as shown in Table 3. It should be noted that ongoing research has found considerable variations in nutrient concentration of phosphorous solids, so a current lab test of the product is essential to calculate appropriate application rates.

Table 3. Elemental composition of phosphorus-rich fine solids. Data obtained from Collins et al. 2016, who also provide a typical pH of these fine solids (pH = 8.0).

Element	Carbon	Nitrogen	Phosphorus	Potassium	Sulfur	Calcium	Magnesium	Iron
g/kg dry weight	197	15	14	13	14	62	14	8

Nutrient Availability: An organic amendment like phosphorus solids requires microbial activity to mineralize the phosphorus and make it available to plants (Leytem and Westermann 2005). Phosphorus solids were found comparable to mono-ammonium phosphate (a standard fertilizer control) in terms of plant availability, in both field and growth chamber studies (Collins et al. 2016). The authors found that 50–60 percent of the total phosphorus applied was plant-available after 3 months under field conditions in the Columbia Basin. Under controlled growth chamber conditions, 24 percent was available after a period of time equivalent to two-months' worth of growing degree days. In this study, phosphorus recovery efficiency values (the phosphorus uptake

of the plant, relative to the available phosphorus) were similar between phosphorus solids and the standard fertilizer control.

Effects on Plant Growth and Yield: Potato plants grown in soil amended with phosphorus solids had similar tuber yield and vine biomass as control plants grown with a standard fertilizer (Collins et al. 2016). However, it should be noted that there was a numerical trend for higher total phosphorus uptake in a standard fertilizer control when compared to phosphorus solids. The authors also found that yield did not respond to increases in application rates of phosphorus solids.

Struvite

Struvite (Figure 7) is a crystalline material derived from liquid dairy manure, with the consistency of sand. Due to its low moisture content, it can easily be transported off-farm for use as a fertilizer for

crop production. Liquid manure (after solids separation) is chemically processed to obtain struvite, which is rich in phosphorus and also contains nitrogen.



Figure 7. Dry struvite product. Photo: Keith Bowers, with permission.

Product Composition: Struvite has a fertilizer formula of 6-29-0+16[Mg]. Its chemical formula is $\text{MgNH}_4\text{PO}_4 \cdot 6(\text{H}_2\text{O})$. The relatively high levels of magnesium may require particular attention when calculating application rates.

Nutrient Availability: Collins et al. (2016) found that struvite applications to potatoes in the Columbia Basin resulted in available soil P concentrations averaging 8, 15, and 20 mg P kg^{-1} for three application rates (32, 60, and 80 kg P ha^{-1}), suggesting that 50 to 60 percent of the P applied

Ammonium Sulfate

Ammonium sulfate (Figure 8) can be recovered from manure after recovery of P solids via an ammonia stripping process in liquid (ammonia solution) or solid (ammonium salt fertilizer) forms. The stripping process is based on raising the pH or the temperature to shift the chemical equilibrium from dissolved ammonium ions towards gaseous ammonia, allowing its removal and collection. The gas stream then requires additional treatment with acid (typically concentrated sulfuric acid) to produce concentrated salt fertilizers, which can also be dissolved in water.

was available after three months. These authors did not provide estimates of available Mg, a micronutrient that is concentrated in struvite (see *Product Composition*, above), and may, therefore, limit struvite application rates. Ongoing (in 2018) struvite field application in alfalfa fields in western Washington have so far shown no indication of Mg issues (Joe Harrison, unpublished data).

Effects on Plant Growth and Yield: Studies evaluating the yield and uptake of P when struvite was applied to triticale, corn silage, and alfalfa have shown struvite to be a good alternative to other sources of N-P fertilizers (Hilt et al. 2016). While not well understood, soil pH seems to be related to the availability of P from struvite, with a greater benefit in low pH soils (Hilt et al. 2016). A separate study compared potato yields from fields where struvite and monophosphate fertilizer (as well as other manure-derived nutrient products) were applied (Collins et al. 2016). The authors found that these two different sources of P performed similarly—higher yield, higher P concentrations in the petioles, and larger tubers than non-fertilized fields—when equal rates of P were applied and the method of application was comparable (Collins et al. 2016).



Figure 8. Ammonium sulfate from processed poultry litter. Photo: Craig Frear, with permission.

Product Composition: Analysis of liquid ammonium sulfate derived from an AD in Washington State found it to contain 3-0-0-4(S) (Chris Benedict, unpublished data). Various forms of ammonium sulfate are commonly used in agricultural production, and typically have higher concentrations of nutrients (e.g., 21-0-0-24[S]) than this product. Additionally, other forms of synthetic nitrogen (e.g., urea 46-0-0) have higher concentrations of nitrogen and, typically, have lower freight and storage costs (James 2010), which make them more attractive to producers. Because this product has a relatively low nitrogen concentration, high application rates are required to meet most crop demands. The need for high application rates and the fact that it is available in

liquid form means ammonium sulfate has the potential to be injected through an irrigation system.

Nutrient Availability: Ammonia stripping of dairy manure is a relatively new nutrient recovery technology (Ma et al. 2013). As a result, there is currently no published research on the nutrient availability of ammonium sulfate derived from dairy manure, but field testing was occurring in Washington State as of 2018.

Effects on Plant Growth and Yield: As with nutrient availability, testing of effects of manure-derived ammonium sulfate on crops was underway as of 2018.

Other Nutrient Recovery Products

There are other nutrient recovery technologies being developed and tested for dairy manure management, including vermicomposting and algal systems. Published data on the composition, nutrient availability, and effects of these products on crops' growth and yield in the Pacific Northwest were unavailable as of early 2018, so these products are not detailed in this publication. However, some research from elsewhere suggests that vermicompost from cow manure (Figure 9) could provide nutrients and improve the growth and yield of crops (Table 4). Similarly, research in Maryland and Florida on algal systems suggest that these systems have the potential to recover nutrients (Mulbry and Wilkie 2001; Wilkie and Mulbry 2002) and replace commercial fertilizers (Mulbry et al. 2005).



Figure 9. Vermicompost using dairy manure. Photo: Darrell Kilgore, WSU.

Table 4. Summary of research on the effects of vermicompost applications on plant growth and yield of a variety of crops.

Crop	Treatments	Location	Effects on plant growth and yield	Reference
Peppers	Commercial vermicomposts made with different feedstocks vs. inorganic fertilizer	Piketon, Ohio	↑ leaf area ↑ plant shoot biomass ↑ marketable fruit weights	Arancon et al. 2005
Tomato	Vermicompost at different application rates vs. inorganic fertilizer	Suzhou City, China	↑ marketable yield at high application rates	Song et al. 2015
Spinach	Vermicompost at different application rates vs. inorganic fertilizer	Suzhou City, China	= marketable yield at high application rates	Song et al. 2015
Rice	Vermicomposts made with different feedstocks applied at different rates vs. no amendments	Seville, Spain	↑ yield at high application rates (two out of three years)	Tejada and Gonzalez 2009

All studies in this table are field studies, and include at least one treatment of vermicompost made from cow manure. The summary of effects on plant growth and yield are focused primarily on cow-manure based vermicompost, though may include other treatments that led to similar effects.

Remaining Challenges and Future Research Directions

Dairy manure-derived nutrient products show promise for meeting crop nutrient needs, while enabling the re-distribution of nutrients from dairies (the source) to cropland systems in need of nutrients (the sink), thereby helping dairies improve whole-farm level nutrient management. However, ongoing research is needed to facilitate wider use and market development for these products.

One primary challenge is the need—from the perspective of the farmer applying them to fields—for these products to have a predictable and consistent nutrient content. Nutrient analysis results carried out during previous and ongoing research on manure-derived nutrient products have varied considerably, based on the dairy the manure is obtained from, and when it was obtained. Producers, therefore, need to obtain a current nutrient analysis prior to application, leading to an added cost and complexity for end users that could hinder widespread use.

Another set of challenges include issues surrounding transportation, storage, and application of these products. Specifically, products such as AD manure, phosphorous-rich solids, and ammonium sulfate, which are liquids or liquid slurries, are expensive to transport long distances. Additionally, their high-water and relatively low-nutrient content would require storage of high volumes of product throughout the year to target optimal plant application windows and to meet total plant nutrient demands. While application of a product like ammonium sulfate could be distributed via current application systems (e.g., center pivot or drip emitters), a product like the phosphorous-rich solids would be difficult to effectively apply via traditional manure spreaders without considerable equipment modification. Partnerships on nutrient recovery technologies between the research community and the fertilizer industry could accelerate progress in overcoming the consistency, transport, storage, and application challenges, and

assist with marketing and distribution of recovered nutrients.

Another major challenge for adoption of these products are issues surrounding food safety in horticultural crops. The perceived potential for pathogens that can affect humans to be introduced into a horticultural crop is likely an impediment to widespread adoption regardless of the beneficial impacts of such products on soil health. Ongoing research in the Pacific Northwest in 2018 is evaluating these manure-derived products in small fruit production, quantifying the potential for introduction and survival of these pathogens. Further evaluation is needed across different production systems and under varying growing conditions to determine to what extent—or under what conditions—food safety concerns can be

alleviated or eliminated. In addition, further changes would be needed in the food processing and marketing industries to alleviate barriers to sale of horticultural products grown using nutrient recovery products.

A handful of nutrient recovery products are already being produced at Pacific Northwest dairies, to address manure management challenges. Meanwhile, many of the product-related challenges are active areas of research in the Pacific Northwest and beyond, which may lead to economically-feasible production of improved byproducts. The results of this research and product development, and increased information about the performance of these nutrient recovery products, will determine whether their widespread use in a variety of cropping systems is practical.

Conclusion

Recycling and reusing nutrients recovered from dairy manure could provide a win-win approach to dealing with manure management issues as well as providing nutrients where needed without further extractive or energy-intensive activities. This is a summary of the current state of knowledge of research and use of manure-based nutrient recovery products. We highlight the challenges that still remain that must be overcome before nutrient recovery products become viable and commonly used. However, research is targeting those remaining challenges, and so far, there is no concrete evidence suggesting they are insurmountable. In addition, for products for which some research has been completed—such as

phosphorus solids and struvite—crop yields appear to be comparable to those using traditional inorganic fertilizers, which suggests that investing in overcoming remaining challenges is a fruitful avenue. Technical and market conditions in the near future will determine whether nutrient recovery products can become part of the solution to manure management issues while improving the economics of production in the northwestern U.S. and elsewhere.

Additional Resources

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