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Solid-Liquid Separation of Manure and Effects on Greenhouse Gas and Ammonia Emissions

Introduction

Solid-liquid separation is a processing technology that partially separates the solids from liquid manure using gravity or mechanical systems. This technology has gained in popularity as it can increase efficiency in manure handling and transport through reduced time and reduced energy use; add value to the manure stream; increase flexibility in the management of manure nutrients; and mitigate environmental impacts related to the storage and land application of manure. The use of separation systems is more likely to occur on larger farms as they handle larger manure volumes and can afford the initial capital costs of these systems. Solid-liquid separation has become complementary to anaerobic digestion systems, where separation occurs after the manure is digested.

Advantages of solid-liquid separation

Separation improves the economics of manure hauling since manure solids can be transported longer distances at lower costs compared to unseparated manure. Additionally, handling volume is significantly reduced while the nutrient concentration is increased. Separated liquids are more easily transported via low capacity pumps and require less agitation in storage than unseparated slurry. In addition, manure liquids can be used to augment or replace fresh irrigation water when solid content is low enough.

Dairy manure is valued for its nutrient content (mainly nitrogen, phosphorus, and potassium), but its land application can be limited due to rules that regulate the volume and nutrients that can be applied per acre. For many crops, manure provides enough phosphorus to meet crop demand, but the nitrogen content in manure is not enough. This results in under-application of nitrogen or over-application of phosphorus. Solid-liquid separation addresses this problem by separating some of the manure nutrients (Table 1). After separation, solids with a higher phosphorus-to-nitrogen ratio can be transported to regions deficient in phosphorus. The liquid stream can be applied locally and possibly at a higher rate.

Separation efficiency is measured by the removal of solids and nutrients from the incoming manure stream. An efficient separator results in separated solids with a high proportion of solid and nutrient (mainly phosphorus) content. Efficiency varies widely and depends on many factors, such as separator type and design, manure type, manure consistency, total solids content, and flow rates. For example, Liu et al. (2016) found that on average 30% of manure phosphorus stays with the solids when a screw press is used, but only 9% remains when a screening drum is used.

Since some volatile compounds (meaning those that are easily degradable) in manure follow the solid stream after separation, solid-liquid separation can reduce greenhouse gas (GHG) emissions and odors from liquid manure storage especially when combined with anaerobic digestion (Aguirre-Villegas, Larson, and Reinemann 2014).

Table 1. Average mass separation efficiency (percentage that follows the manure solids) of total solids, nitrogen, and phosphorus in manure by mechanical separation.

Component	Mass separation efficiency (%) ¹
Total solids	45
Total nitrogen	18
Organic nitrogen	20
Inorganic nitrogen	15
Total phosphorous	21

¹ From Chastain (2013) based on (Gooch, Inglis, and Czymmek 2005; Chastain, Vanotti, and Wingfield 2001)

Drawbacks to solid-liquid separation

Disadvantages of adopting solid-liquid separation include associated capital, operational, and maintenance cost requirements that may not be feasible for small or even some large operations. The additional equipment needed to handle both manure solids and liquids for collection, storage, and land application can increase costs and may require more labor. Incorporating these components may also require more space on the farmstead.

Process outline and end products

The separation process begins with the collection of dairy manure and subsequent transport to the separation equipment. The separation equipment divides manure into solid and liquid streams via gravity or mechanical systems (Figure 1). After separation, the solid stream is usually stacked and

temporarily stored, and the liquid stream is transported, mainly by pumps, to long-term storage (Figure 2). Separated solids have been traditionally used as a fertilizer or soil amendment on-farm or exported to neighboring farms that have a demand for the additional nutrients.

Separated solids can also be used as bedding material when processed in a digester, composted, or heated in bedding recovery units, as pathogens can be inactivated when heated (Burkholder et al. 2007). When using manure solids for bedding, it is recommended to increase the frequency of bedding replacement to the stalls and to use practices to reduce moisture content. These practices help avoid regrowth of pathogens that can impact herd health. The liquid stream is stored until it is applied as fertilizer, usually in spring and fall.

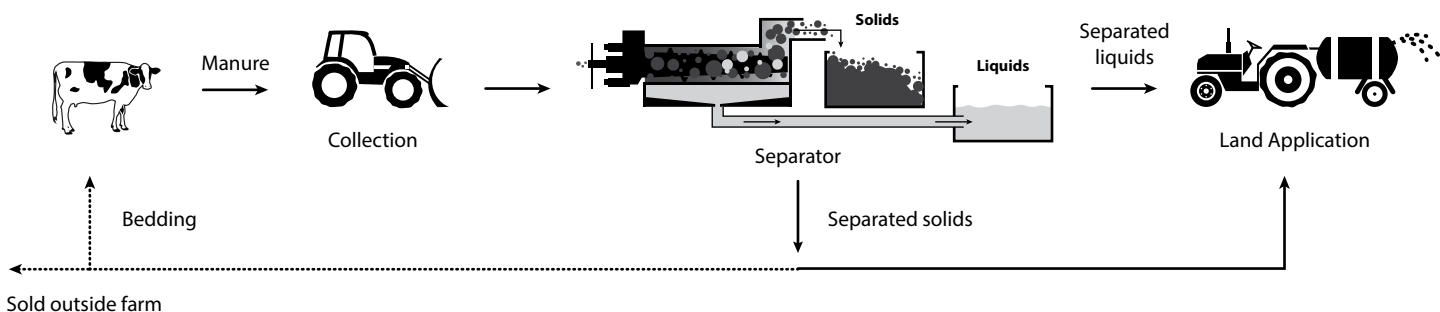


Figure 1. Solid-liquid separation of dairy manure. Dotted lines represent alternative options for use of separated solids.



Figure 2. a) Separated solids, and b) separated liquids.

Separation technologies

The most common solid-liquid separation technologies include gravity-driven systems and mechanical separators. Gravity systems, also known as passive systems, are relatively simple and low-cost as they rely on gravity and time for solids to settle. The most common gravity systems are settling basins and ponds. The resulting products are liquid manure at the top, which can be pumped or drawn off, and a thicker slurry at the bottom, which can be left to dry in a holding pond and then removed (VanDevender 2016). The advantage of this type of system is reduced moisture content in the manure solids since they are allowed to dry prior to removal (Chastain 2013). Despite their advantages, these systems require more area and potentially more labor than mechanical separators.

Mechanical systems, also known as active systems, involve the use of equipment that applies force to separate manure solids from liquids. Mechanical separators have low maintenance requirements, compact designs, and require less land area than gravity systems. Some of the most common mechanical systems include rotating, vibrating, and stationary inclined screens; roller, belt, and screw presses; and centrifuges and hydro-cyclones (Figure 3).

A stationary screen is mounted on an incline where manure enters the screen at the top. As manure moves down the screen, the liquids pass through the screen while the solids move down toward the lower end. This is considered the simplest and cheapest system, but is prone to clogging problems (Chastain 2013). In a vibrating screen system, solids are vibrated to the edges of a screen, which reduces cleaning requirements. A rotating screen system uses a screen attached to a spinning drum that allows the liquids to pass through while the solids are retained outside of the drum. This screen design is small but requires more energy than the other screen systems (Chastain 2013). A press uses significant pressure against a screen to separate solids; however, too much pressure may force the solids to pass through the screen along with the liquids. A centrifuge consists of a cylinder that spins at a high velocity to separate solids from the liquid. In general, centrifuges achieve the highest separation rates but are also usually the most expensive option (Hjorth et al. 2009).

Other less common separation technologies include drying and chemical separation. Drying can be done in evaporation ponds and dehydration systems, but the use of these systems is limited by their low efficiencies, high initial costs, maintenance, and energy requirements (Mukhtar, Sweeten, and Auvermann 1999). Chemical separation uses coagulants or flocculants that make small particles in manure stick together to form larger particles. This facilitates the separation process and also helps target the separation of certain compounds (VanDevender 2016). However, the addition of chemicals increases operating costs since chemicals must be purchased on a continual basis. Separation efficiencies may also be improved by using numerous technologies in series, such as adding chemicals after mechanical separation.

Greenhouse gas and ammonia emissions from manure handling with solid-liquid separation

Installing a manure solid-liquid separator can reduce GHG and ammonia emissions during manure storage and after land application when compared to manure handling without processing. A separator reduces GHG emissions through multiple pathways. First, methane emissions from liquid manure storage are reduced since the compounds responsible for these emissions (volatile solids) are separated along with the solid stream (Aguirre-Villegas, Larson, and Reinemann 2014). Second, if manure solids are stored, the aerated conditions that exist during this storage limit the emissions of methane. Third, the separation process removes the fibrous and large pieces of organic material from the manure liquid fraction, which prevents a natural crust from forming on top of the stored liquid. A natural crust can create aerobic conditions that promote nitrate production near the surface. Nitrate can then be converted to nitrous oxide, a GHG that is 264 times more potent in warming the Earth than carbon dioxide (Rotz et al. 2015). Without a natural crust



Figure 3. Separator types: a) Centrifuge, b) screw press, and c) rotating screen.

storage conditions are anaerobic, which will prevent nitrate from forming, thus reducing nitrous oxide emissions from liquid manure storage.

GHG emissions from manure management can be reduced by 19% when solid-liquid separation is used (Figure 4). While there is an increase in fossil GHG emissions from electricity consumption when the energy matrix is based on fossil fuels (e.g. coal), the increment is negligible when compared to the manure emission reductions.

Ammonia emissions from storage of the liquid stream can increase after solid-liquid separation due to the lack of a natural crust on top of the storage (Rotz et al. 2015). This crust constitutes a barrier for wind that promotes nitrogen volatilization (gas lost as ammonia). Despite the increase during storage, total ammonia emissions from manure

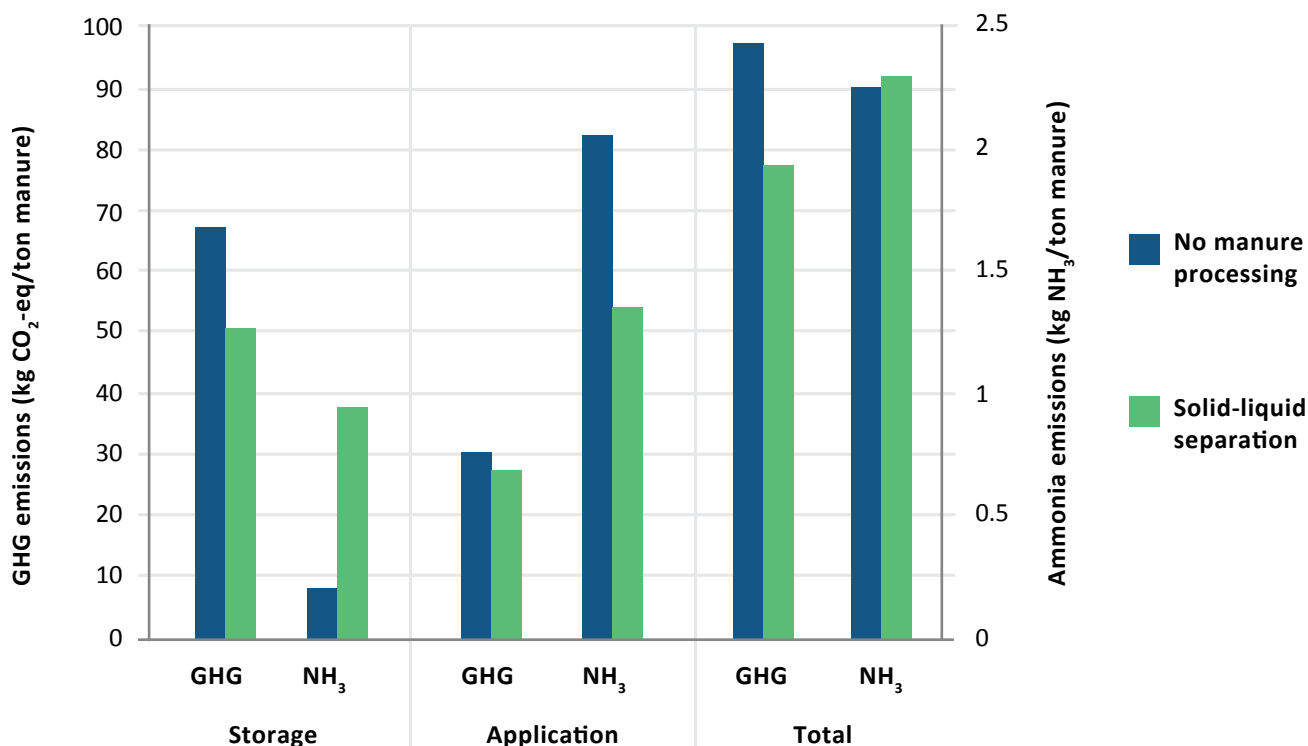


Figure 4. Comparison of total greenhouse gas (GHG) and ammonia (NH₃) emissions from manure handling at a dairy farm without any manure processing and a farm with solid-liquid separation (source: Aguirre-Villegas, Larson, and Reinemann 2014).

management in systems with solid-liquid separation remain the same as in systems without separation since the ammonia emissions after application are reduced (Figure 4) (Aguirre-Villegas, Larson, and Reinemann 2014). This reduction is attributed to a more effective infiltration of inorganic nitrogen into the soil since the organic material in the liquid manure stream is decreased during separation. Some practices to reduce ammonia emissions include installing a manure storage cover and injecting manure into the soil instead of applying it on the surface.

When coupled with anaerobic digestion, ammonia emissions after solid-liquid separation could increase significantly if the manure storage is not covered and if manure is not injected. This is because the digestion process makes nitrogen more available to crops but also more prone to volatilization. It is important to implement manure management practices that reduce ammonia emissions.

Summary

Solid-liquid separation divides manure into solid and liquid streams through gravity or mechanical systems and provides economic, technical, and environmental benefits in manure management. The solid stream, which has a higher nutrient density, can be used as fertilizer, soil amendment, or bedding on-farm or exported to neighboring farms. The nitrogen-rich liquid stream generally is applied locally as fertilizer. GHG emissions from the storage of the liquid stream are reduced compared to a system without separation as the compounds

responsible for methane emissions are separated with the solid stream. Moreover, the solid stream is stored in stockpiles, where the aerated conditions limit the potential for methane to be emitted. Ammonia emissions from storage of the liquid stream can increase after solid-liquid separation due to reduced solids that would otherwise lead to crust formation, but the net effect is neutral due to a better infiltration of the liquid manure nitrogen after being applied to the soil.

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