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Manure as a Natural Resource

Alternative Management Opportunities

Manure, as a source of organic matter and plant nutrients, is an excellent conditioner for soils. It is a component of agronomic production, cycling nutrients between soils, plants and livestock. However, in areas where limited land is available for application, excess soil nutrients can lead to water quality issues.

Local restrictions on manure application necessitate finding alternative uses. The simplest method is to transport manure to nutrient-deficient land. Manure can be composted into a higher-quality fertilizer or have the nutrients extracted and sold separately. Manure also has an energy value, and where feasible, anaerobic digestion, pyrolysis, or gasification could be options.

Shipment to Nutrient-deficient Regions is Simplest Solution for Dealing with Excess Manure

The major restriction to transporting manure is the cost of hauling and handling. As fuel costs rise, the distance you can ship manure will decrease [1, 2]. Transporting manure is only feasible if the price of commercial fertilizer rises enough to make hauling manure a cheaper option [1]. The future scarcity of rock phosphate provides us with motivation to recycle phosphorus locally [1]. Therefore, any improvement in manure transport may offset future global shortages in fertilizer for the Mid-Atlantic region.

Based on 2009 commercial fertilizer prices, the University of Georgia determined that poultry litter had an estimated value of $80/ton [3]. However, poultry litter was sold at $10-55/ton, reflecting actual demand. The contrast between the estimated value and the actual price could be due to limited understanding of the full value of chicken litter, which includes both nutrients and organic matter. To make transporting litter profitable, public policy would need to subsidize and promote it, similar to the Maryland Department of Agriculture Manure Transport Program [2, 4].

Common methods of transporting manure include truck, rail, and barge [2, 5, 6]. In Europe, pipelines also have been proposed to move liquid manure slurries [7]. One way to increase transport distance is to reduce the volume of manure and concentrate the nutrients. While maximum profitable distances of raw manure transport can be 30-40 miles [8], concentrating nutrients could expand the distance to 185–260 miles [5, 9].

There are several methods of concentrating nutrients, including mechanical (**pelletizing, baling**) and biological (**composting**). However, any additional processing of manure will incur its own costs and should be considered accordingly.

Pelletizing Compacts Manure Using High Temperatures and Pressure to Create a More Uniform, Dense Product

Due to their density, a larger amount of pellets can be shipped compared to raw manure, easing storage and transportation [12, 13]. However, the need for a large drier means on-farm pelletizing is usually not cost effective [10, 11].

Nutrients can also be added to the pellets, enhancing their agronomic value. Costs associated with the pelletizing process can be up to $40-50/ton [2, 12] and the pellets may have an estimated value of $100/ton [2]. Any additional handling of manure will have energy and other associated expenses, which could annul the savings in transport.

Baling is Another Option for Pre-packaging Manure

Baling and wrapping poultry litter with plastic has been tested in Arkansas where baling litter was cheaper than other options, costing only $5-10/ton [2, 6]. Barge transportation on the nearby Mississippi River made shipping baled litter economically feasible over long distances [6].

Bales can also can be shipped on flat-bed trucks, removing the need for specialized trailers. The use of flat beds lowers the cost of shipping by enabling backhauling where a trucker returns to the originating point with a full load [1]. Since it costs almost as much time and fuel to drive empty as fully loaded, backhauling makes economic sense. However, a successful litter baling company was not operating when this report was published.

Composting is a Well-known Solution to Manure Handling, Particularly for Reducing Odors and Pathogens

Compared to pelletizing or baling, composting can be a much simpler process, requiring only a bucket loader and storage space. When performed correctly, composting encourages microorganisms to break down the manure (figure 1), causing a reduction in total mass [14, 15]. Benefits include improved handling, odor and transportation. However, these benefits may be offset by additional costs, including bulking agents, storage space, and the loss of nitrogen [15].

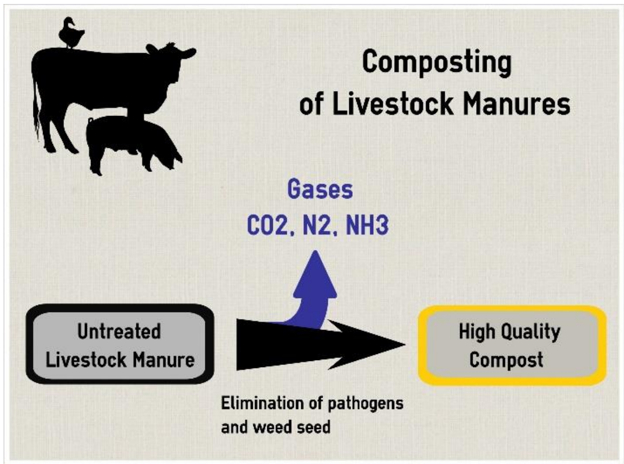


Figure 1. Composting encourages microorganisms to break down manure

Bulking agents (materials high in carbon, such as wood chips, straw) are used to increase the quality of composts. When feeding on manure, microbes prefer good moisture, a pH 5.5-8.0 and temperatures greater than 130°F. In addition, the microbes require 30 carbon (C) atoms for every one nitrogen (N) atom, which is known as the C:N ratio [15].

Not all livestock manures have the same C:N ratio, especially if they are mixed with different types of beddings. If a manure (for example, chicken litter and pine shavings) has a C:N greater than 30, the compost may be ineffectively broken down. On the other hand, excessive nitrogen (C:N less than 20) may limit composting, since high levels of ammonia are toxic to microbes. Therefore, bulking agents (cereal straw, pine shavings, dry switchgrass) can be used to adjust C:N ratios as well as moisture content.

Phosphorus and potassium are concentrated by composting, but nitrogen can be lost as a gas. The reduced odor, pathogens, and ease of handling can make up for nitrogen loss. For more information on composting, see University of Maryland Extension publication, *Backyard Composting* (HG-35).

Table 1. Transporting manure as pellets, bales, or compost

Benefits
Moves nutrients to needed areas
Cycles nutrients in the region
Costs
Fuel limits transport distance
May require additional equipment
May require additional inputs

Manure, as an Organic Material, Can be Used to Produce Energy

Methods of energy production can be biological (**anaerobic digestion**) or use heating (**incineration, pyrolysis, or gasification**). Energy production is more labor- and capital-intensive than composting and, unless it is done of the farm, will include transportation and maintenance costs.

Anaerobic Digestion is a Tested Practice

Anaerobic digestion refers to the microbial breakdown of organic materials under anoxic (lack of oxygen) conditions. Many microbes require oxygen, but there are others who have adapted to anoxic environments. The smell of sulfur and methane from marshes are a sign of anaerobic microbes living in saturated, low-oxygen soils.

A valuable resource produced from anaerobic digestion can be a biogas like methane (CH_4), which can be burned to produce heat or energy [16]. Fertilizer is another byproduct of anaerobic digestion, produced from the remaining "digested" manure or liquid effluent. Similar to composting, nutrients like phosphorus and potassium are more concentrated in the fertilizer byproduct than in raw manure, but very little nitrogen is lost [17-19].

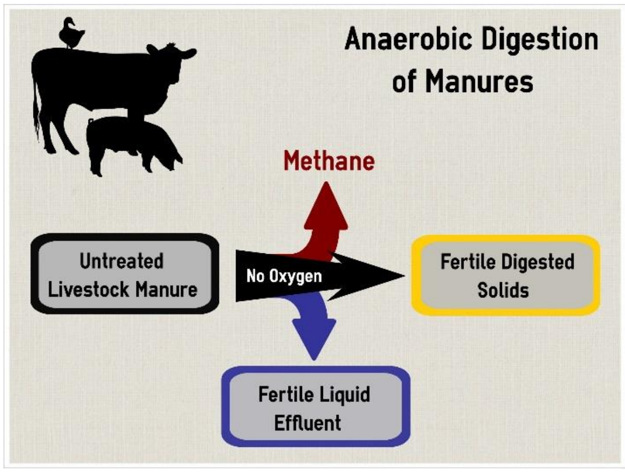


Figure 2. Fertilizer and biogas are valuable byproducts of anaerobic digestion

The solid content of manures is an issue in anaerobic digestion. If a manure contains 5-20% solids (e.g. poultry litter), anaerobic digestion may be limited by the large amount of solid waste that microbes need to process [19-21]. Large solid loads can also mean higher ammonia levels, which are toxic to anaerobic microbes [19, 20]. Diluting manure to 0.5 to 3% solids is suggested, but the addition of water increases the total waste volume [17, 21].

In addition to the total ammonia content, the C:N ratio is important. A C:N ratio greater than 30 can reduce biogas production, while a C:N less than 20 will promote ammonia accumulation [19]. Livestock manures with greater cellulose or lignin content also require longer retention and have lower methane production due to the increased time it takes to break the manure down [19, 22]. Other conditions that limit anaerobic digestion include:

volatile fatty acid content; pH (optimum is 5.5 to 8.5); heavy metals; antibiotics; and temperature [19, 23]. Livestock manures can be mixed together with sewage sludge, household waste, or industrial byproducts [19, 20]. Mixing manures can improve digestion by improving moisture balance and lowering ammonia [16]. Mixing can also provide inoculation, since ruminant and manures stored in pits may already have necessary anaerobic microbes to kick-start digestion [20, 21]. However, these inoculant microbes may still need a 3-60 day incubation period to adapt to fresh manure [21].

In general, co-digestion should be done to balance solids and ammonia content. Dairy manure has a high methane potential, but would need to be mixed with a drier material to maintain methane production [22]. Poultry litter, with greater dry matter and ammonia, can be mixed with swine wastes, which have a lower solid and ammonia content [19]. Reducing the solids content of manure to less than 10% works well, while diluting to 5% solids will produce the highest methane levels [21].

Mixing manures may have other issues to consider, such as the accumulation of scum and solids when poultry and hog waste are mixed [19]. The amount of biogas produced is also important, as poultry can yield more methane than cattle or swine manure [17].

The most obvious issue with co-digestion is access to other manures. Poultry is concentrated on the Eastern Shore and dairy in the western counties of Maryland, so transportation will limit the ability to mix these manures for anaerobic digestion [19]. Adding municipal solids, a simple dilution, or higher lignin (cereal straw, sawdust, switchgrass) may be more feasible [22]. Mixing 40% fresh manure with 60% digested sludge can result in thorough digestion [21].

Figure 3. Dairy cows may not only produce milk, they also may contribute nutrients and energy from their manure.

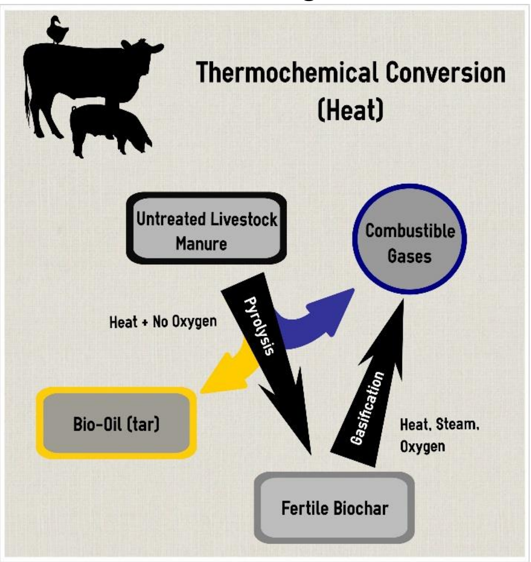
Other limitations of anaerobic digestion include the capital costs and space. Anaerobic digesters require designated space, facilities and equipment. Those costs can be offset by energy production or selling the digestate as fertilizer. As a fertilizer source, digestate would be high in moisture and would require following nutrient management guidelines. A thorough analysis of costs and inputs should be done before undertaking a project of this size.

A study by the University of Maryland found that economically viable digesters worked on 250-cow dairy farms when cost sharing was implemented [24]. Using the remaining digested material as animal bedding produced the highest revenue stream from these digesters, followed by biogas and carbon credits.

Thermochemical Conversion: Heating Manure Using Incineration, Pyrolysis and Gasification

Burning manure (incineration) is a simple method, but more complex processes (pyrolysis and gasification) also have been developed (figure 3). A major benefit of using thermochemical conversion (TCC) is the speed of the process [17, 25]. While composting can take 4-6 weeks and anaerobic digestion up to a few months, TCC can be done in as little as a few hours. The primary reason for performing TCC is to produce energy, either through heat or gas production [17, 25-27].

Figure 4. Thermochemical conversion is a technical term for heating manure



Oxygen is a Necessary Component of Incineration

Burning manure, also known as combustion, can be done to heat poultry houses [17]. The ash from incineration is sterile and still contains phosphorous, potassium, and calcium, so it can be used as a fertilizer. The major drawback to incineration is the emission of gases (CO_2, NO_x, SO_x) and ash into the atmosphere. The moisture content of manures reduces their energy value, so dry poultry litter would have more value than lagoon manure [17, 26].

Pyrolysis Heats Manure in Air-tight, Zero-oxygen Ovens

The lack of oxygen in the pyrolysis process keeps the manure from turning to ash. Instead, tar, combustible gases and charcoal are formed [27, 28]. The tar can be condensed into a bio-oil and the charcoal is often referred to as biochar [25]. The bio-oil and the gases are burned to create heat or energy; however, bio-oil is highly oxygenated and may have to undergo further processing before it can be used [25-27].

Energy can also be created from biochar through the gasification process (figure 3) [29]. Up to 50% of the energy is contained in the biochar and 25% in the combustible gases [27]. Not all animal manures will produce the same amount of energy. For example, biochars from dairy manure may have greater energy content than other livestock wastes [30].

When it is not used for energy, biochar also can be used to improve the organic matter, fertility and water-holding capacity of soil [31]. Manures can be combined together or with plants (swtichgrass, etc.) to create high-carbon or high-phosphorus biochars [30, 31]. If a landowner would like to build up soil carbon but not phosphorus, the higher phosphorus in swine chars would not be a good option but switchgrass would [30]. Therefore, the end use of biochar (e.g. energy, soil conditioner) should be considered when choosing the feedstock for pyrolysis.

When dealing with livestock manures, pyrolysis has limitations similar to composting and anaerobic digestion. While C:N ratio has no effect on pyrolysis, moisture content can increase operating costs [27]. More energy would be needed for swine (liquid lagoon) than poultry manure, unless the swine manure is dewatered or combined with drier materials (e.g. poultry litter, rye grass) [27]. Recycling heat within these systems is recommended, and combustible gases could be used to dry new manure inputs [25]. Additionally, capital/operating costs, access to manures, and transportation will limit pyrolysis [17]. On-farm operations will require maintenance and expertise, but the feasibility of regional processing depends on source and transport costs.

While costs will limit application, there are many positive points about pyrolysis, including its: 1) smaller footprint; 2) nutrient recovery; 3) energy production; 4) short processing time; and 5) pathogen elimination [25].

Gasification Holds Promise of Partnerships between Agricultural and Coal Industries

Gasification is sometimes used by the energy industry to produce combustible gases from coal. The biochar produced from pyrolysis is similar to coal and could undergo gasification, producing additional combustible gases [25]. Air, oxygen, or steam is used in gasification to produce CO, CO_2, and CH_4 at temperatures of 800-900°C [25, 28, 32]. This fuel could be used in gas engines or turbines [28]. Like pyrolysis, heat from later stages can be used for initial drying of manures, which will help recycle energy [25].

Gasification has the same issues as pyrolysis--capital, maintenance and transportation. In addition, due to the high nitrogen content of manures, nitrogen gas may dilute the combustible gases, producing a lower-quality product [28, 32]. However, biochars from manure could be co-combusted or gasified with coal, reducing some potential issues and resulting in certain economies.

Table 2: Using manure for energy in anaerobic digestion, incineration, pyrolysis or gasification

Benefits
Energy production
Shorter processing times
Kills pathogens/breakdown antibiotics (sterile)
Byproducts can still be used as fertilizer
Costs
Capital costs (infrastructure, labor)
Requires specific expertise
Anaerobic digestion requires steady inputs
Incineration can create air pollution

Nutrient Extraction Could Mean Increased Use of Manure or Biochar on Production Fields

Nutrient management is an ongoing consideration in the Chesapeake Bay watershed. Even though nutrients may be retained in anaerobic digesate or biochar, their phosphorus content may prevent application to nutrient-saturated fields. A possible solution would be to extract the nutrients from livestock manures. If phosphorus can be preferentially extracted from raw manure or biochar, the remaining organic material, including the residual nitrogen, could be applied to land [33, 34].

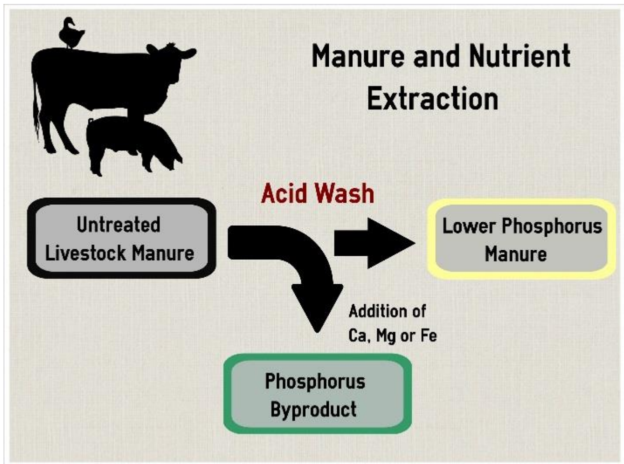


Figure 5. Extraction processes result in lower phosphorus manure

There are physical (membrane filtration) and chemical extraction methods [34, 35, 36]. Nitrogen has been recovered from sludge using membrane filtration, but P extraction only worked at low pH [35]. Gas permeable membranes (which only allow the passage of specific gases) have been used to successfully extract ammonia from liquid swine lagoons and the air of poultry houses [37, 38].

Chemical extraction using acids (sulfuric, citric), ferric chloride, or chelating agents (EDTA) also can be used. Mineral or organic acids extract up to 60% of phosphorus from poultry litter, creating a more balanced N/P ratio (in the manure) for crop uptake [34].

After nutrients are extracted as an effluent, Ca, Mg or Fe can be added to crystallize phosphorus into a solid [33, 34, 36]. Struvite is a common byproduct of anaerobic digestion that can be sold as a phosphorus source [36]. Extracted nutrients will have a lower mass and volume than raw manure, can be readily used by crops, and could be transported longer distances [33, 34]. Any use as a fertilizer would still have to follow nutrient management regulations. In addition, when extracting N and P from char waste, heavy metals can also be released [36], so any product sold as a fertilizer would have to be tested for metal content.

Table 3: Extracting nutrients from manure using physical filtration or chemical methods

Benefits
Manure lower in phosphorus can be land applied
Extracted nutrients can be shipped and sold
Costs
Capital costs (infrastructure, labor)
Requires specific expertise
Chemical extraction uses acids

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