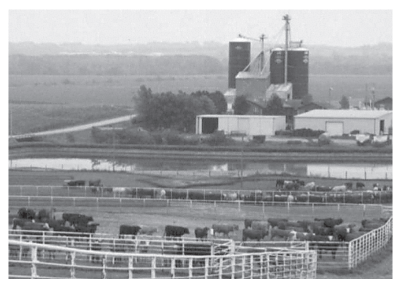
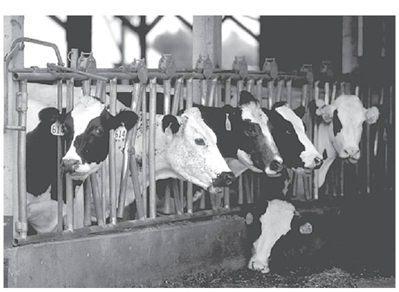
Lesson 25

Manure Treatment Options

By Frank Humenik, North Carolina State University





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Intended Outcomes

The participants will

- Understand basic principles of manure treatment to evaluate alternative technologies.
- Identify desired outcomes of manure treatment and ability of alternative technologies to accomplish these outcomes.

Contents

PROJECT STATEMENT

This educational program, Livestock and Poultry Environmental Stewardship, consists of lessons arranged into the following six modules:

- Introduction
- Animal Dietary Strategies
- Manure Storage and Treatment
- Land Application and Nutrient Management
- Outdoor Air Quality
- Related Issues

Note: Page numbers highlighted in green are linked to corresponding text.

Activities

The participants will determine which system may meet their current or future needs.

Goals/Objectives of Treatment Systems and Alternative Technologies

Animal manure treatment systems have historically been selected to recover or use valuable fertilizer constituents or feed ingredients and to protect soil, air, and water quality. Over time, however, the protection of soil, air, and water quality has evolved to include such considerations as the management of potentially toxic materials such as copper, zinc, and antibiotics; concerns about proper nutrient management; and increased emphasis on air quality. Odor; ammonia volatilization; the release of hydrogen sulfide, methane, and other gases; and the potential of dust to transport odors and produce biosolids have become major public concerns. There has also been increased emphasis on the utilization of valuable constituents in manure and mortalities through more effective constituent conservation and processing to value-added byproducts.

Manure treatment systems or alternative technologies are evaluated or selected for their capability to provide the required protection of soil, water, and air resources. Some waste treatment systems or alternative technologies can address several of these requirements, while some are so specialized that only individual resources or waste constituents are addressed. A discussion follows of environmental quality concerns and waste treatment systems or alternative technologies required to protect resources or address particular waste constituents or waste management needs or desires.

Manure treatment systems or alternative technologies are evaluated or selected for their capability to provide the required protection of soil, water, and air resources.

Water quality considerations

Animal manure constituents such as organic matter, nutrients, nitrogen (N), phosphorus (P), pathogens, and metals can degrade surface water quality and thus must be removed by waste treatment systems or managed by alternative technologies either in conjunction with existing waste treatment systems or as a new waste management system.

Organic matter. Organic matter supports the metabolism of aerobic or anaerobic microorganisms. When animal manure with high amounts of organics is discharged to receiving waters, rapid microorganism growth occurs that depletes the receiving waters of oxygen, causing either low or zero levels of oxygen to exist and thus either anaerobic or septic conditions to develop.

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) tests are standard wastewater analyses that determine the level of oxygen demand. Strict regulations limit the amount of BOD or COD that can be discharged into receiving streams. Since it is difficult or impractical to obtain these effluent levels with traditional animal waste treatment systems, animal waste is generally not discharged but terminally applied to land as an alternative to commercial fertilizer.

Manure organics and oxygen demand can be reduced by processes that promote the growth of either aerobic or anaerobic bacteria. Under aerobic conditions, 50% of the metabolized carbon (C) goes to biomass, which can be removed by settling. However, this settled biomass or sludge requires further management because of its nutrients and possible harmful constituent contents. Under anaerobic conditions, 90% of the C is released as methane and carbon dioxide. Therefore, with anaerobic treatment, less biomass is generated and methane can be used as an energy source for hot water and electricity.

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Nutrients. The animal waste nutrients of primary concern are N and P. Historically, animal waste has been applied to land, taking advantage of these fertilizer nutrients. However, regulations have been developed or are being developed that require animal waste N and P to be applied at agronomic rates because excess levels are building up in soils and being transferred to surface waters by runoff and to groundwater by infiltration. If sufficient land is not available to apply N and P at agronomic rates, then alternative technologies must be added to the existing waste treatment system or new alternative technologies employed to either use or reduce the amount of N and P. Effluent from conventional biological treatment processes may contain high amounts of phosphate, ammonia, and N because of the limited uptake of these constituents by microorganisms.

Nitrogen (N). Nitrification, the conversion of N to nitrate for conservation as fertilizer N, is becoming an increasingly important component of total farm management systems. High-rate oxidation of manure N to nitrate can also reduce ammonia volatilization.

Nitrogen can be removed by denitrification, which is the conversion of nitrate to N gas under anaerobic conditions when sufficient organics or energy is available. Manure N can be oxidized to nitrates by various aeration techniques, such as lagoon aeration by a surface aerator or compressed air released as small bubbles near the bottom of the lagoon, aerobic bio-filters, sequencing batch reactors (SBRs), and other nitrification treatment systems. Once N is in the nitrate form, transformation into N gas needs two conditions: a source of C and an anaerobic environment.

A lagoon can be partitioned so that the initial part is aerated to convert N to nitrate; then the nitrate can be denitrified to release N gas in the secondary, unaerated portion of the lagoon. Aeration requirements for producing nitrate in an animal waste lagoon vary from satisfying about one to two times the amount of BOD or about one-half of the total COD. Aerated biofilters can be packed with plastic media to provide increased surface area for the microorganisms responsible for treatment to develop at the media surface, forming a biological film. The air bubbles that travel upward through the media provide the oxygen necessary for these microorganisms. With sufficient aeration, the removals obtained can be as high as 90% for BOD and 75% for COD, and ammonia can almost be completely converted to nitrate. The nitrate can then be converted to N gas by denitrification in a following unit that is anaerobic and has sufficient energy. It is possible to remove a large amount of the N as N gas with such a series treatment system.

An SBR is a containment vessel that is operated sequentially as an aerobic and anaerobic unit. It can remove up to 90% of the COD, and ammonia can be almost completely converted to nitrate, which can then be denitrified to N gas under anaerobic conditions. Therefore, the SBR is a single reactor that provides waste stabilization by reducing the COD and also N by sequential nitrification and denitrification.

Phosphorus (P). Phosphorus removal is becoming more important as guidelines and regulations are developed that limit animal manure application to agronomic rates for P. Therefore, processes that provide for biological uptake of P such as an SBR or removal of P by chemical precipitation as in municipal and industrial wastewater treatment are being evaluated for their application to animal wastewater treatment. An SBR is able to remove about 40% to 70% of the total P during short, cyclic aerating/non-aerating periods. Phosphates are biologically removed under cyclic aerobic/anaerobic conditions because the bacteria's overall rate of P absorption is greater than the release rate, resulting in net P removal from the wastewater when the bacteria are settled out as solids or sludge.

Phosphates can be removed from wastewater by chemical precipitation using multivalent metal ions such as iron, aluminum, and calcium. This process results in phosphate precipitates that can be removed by settling; with proper pH adjustment, a high degree of phosphate removal can be achieved. Processes that remove P as calcium phosphate by precipitation provide a product that adds both lime and P when applied to soils, thus serving as a waste utilization technology.

Pathogens. Animal manures are a potential source of human and animal pathogens. Among the pathogens of concern are escherichia coli (*E. coli*), salmonella, giardia, campylobacter, and cyptosporidum parvum (*C. parvum*), which can be transferred from animals to humans. Recently, the presence of the toxic pfiesteria piscicida in East Coast rivers and estuaries was attributed to the presence of excess nutrient sources, some of which may be from animal production areas or from runoff in areas where animal manure is land applied. Documentation of the fate and transport of human pathogens from animal production/manure management systems requires extensive research.

The level of pathogens remaining after treatment or land application has received additional attention as increased emphasis is placed upon food safety and public health. Generally, pathogen destruction increases with increased exposure to air or sunlight or adequate retention time in manure treatment processes. Thus, manure treatment processes that provide these features result in increased pathogen removal. However, the relationships between exposure to any resulting disease and actual public health impacts remain difficult to define.

Heavy metals. Heavy metals and other nonbiodegradable feed ingredients may be present in either the liquid or solid stream of livestock and poultry manure. Alternative technologies can be used to selectively remove these metals from either stream if their level causes problems or increased costs for utilization strategies and terminal management by land application at agronomic rates for N and P.

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Air quality considerations

Odors and gases of environmental concern such as methane, hydrogen sulfide, and ammonia are formed under anaerobic conditions during manure storage or treatment. The release of these gases can be reduced or eliminated by reducing or eliminating atmospheric exposure with covered lagoons or enclosed vessels. The reduced gases resulting from anaerobic conditions can be oxidized by aerobic treatment processes to stable end products such as nitrate, sulfate, and carbon dioxide.

Research and field experiences have shown that odor intensifies as lagoon loading increases. Therefore, the lagoon loading rate can be reduced by adding less waste or increasing lagoon size. Anaerobic lagoons can also be aerated by floating surface aerators or by compressed air discharged through defusers located near the bottom of the lagoon, which provide small bubbles for maximum oxygen transfer. The recommendations for odor control using surface aerators are to provide sufficient oxygen transfer to satisfy from half to the full input COD. However, aeration may also increase ammonia volatilization. Therefore, recommendations that provide partial aeration to satisfy odor are being reexamined. More intense aeration to provide one, one

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Data indicating that more odors come from the production unit rather than from the manure management system are causing more attention to be focused on techniques that reduce in-house dust and odors and treat ventilation exhaust air.

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One of the first processes in... wastewater treatment is removal of large solids... .

and a half, or two times the COD may be recommended to convert ammonia to nitrate, which also controls the release of reduced gases such as methane, ammonia, and hydrogen sulfide. The oxidized nitrate can be denitrified or converted to N gas under anaerobic conditions if sufficient energy is available for this biological process. Therefore, ammonia volatilization can be reduced by providing aerobic conditions that enhance the oxidization of ammonia to nitrate and then N can be removed by providing an anaerobic process that converts nitrate to N gas.

Many other treatment processes can reduce loading to an anaerobic lagoon. The municipal and industrial waste treatment processes commonly used for the biological oxidation of reduced products to stable end products can also be used to reduce the air quality impacts from livestock and poultry waste treatment systems. Many of these unit processes are discussed in the section titled "Alternative Treatment Technologies Case Studies." The performance, cost, and ability of these treatment processes to reduce odor are compared in Appendix B, Tables Comparing Alternative Manure Treatment Technologies.

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Basic Principles of Manure Treatment

Many of the alternative and advanced manure treatment technologies being recommended and tested for livestock and poultry manure are already being used for municipal and industrial waste. Often, these technologies use basic principles to reduce odor and ammonia volatilization and provide alternatives to lagoon systems. In fact, several of these technologies can both reduce odor and ammonia volatilization and provide increased nutrient removal for either existing or new systems. Therefore, it is important to understand the basic principles of manure treatment and to determine the system that best meets a given need.

This section covers the basic principles of alternative and innovative technologies. A description of major alternative and advanced treatment technologies and tables (Tables 25B-1, -2, and -3) that compare their capability to reduce odor, oxygen demand, N, P, and pathogens are contained in Appendix B. Case studies are presented in the last section, which provides more information about the capability of these technologies to meet different manure treatment goals.

Solids removal

One of the first processes in municipal wastewater treatment is removal of large solids by gravity in a grit chamber. Similar basins have been used for solids removal from feedlot runoff or before lagoons. Generally, two parallel basins are built so that while one is in use the other one can be draining, enabling workers to remove solids with a front-end loader by using a sloped access area. Smaller solids can be removed in a sedimentation tank where velocity is greatly reduced, allowing significant removal of solids that settle under the design conditions used. In general, however, sedimentation tanks are not used for animal manure treatment because of the large size required, which results in high construction and operational costs.

Solids removal technologies also include simple incline screens, self-cleaning screens, presses, centrifuge-type processes, and rapid sand filters. These types of separators are being used for animal manure treatment and can reduce C, N, and P loads to subsequent treatment units.

Table 25-1 depicts the performance of mechanical separators.

Sedimentation

Biosolids or generated biomass from biological treatment can be removed in a sedimentation tank or clarifier where the flow velocity is not sufficient to keep a certain size or weight of solid in suspension. Some of these processes, such as a biofilter, must have the accumulated biomass periodically removed

Table 25-1 Mechanical separator performance.

Type of Mechanical Separator by Animal	Screen Opening, mm	TS in Raw Manure, kg/l	Separation Efficiency, %					TS in Solids, %	Liquid Flow Rate, l/m
			TS	VS	COD	TKN	TP		
Stationary									
Swine	1.5	0.2-0.7	9	-	24	-	-	6	235
	1.0	0.2-0.7	35	-	35	-	69	-	-
	1.0	1.0-4.5	6-31	5-38	0-32	3-6	2-12	5	-
Dairy	1.68	4.6	49	-	-	-	-	12	-
Beef	0.5	0.97-4.1	9-13	-	-	-	-	13-22	-
Vibrating									
Swine	1.7	1.5	3	-	6	-	-	17	37-103
	0.841	1.5-2.9	10	-	1-14	-	-	18-19	15-103
	0.516	1.8	27	-	24	-	-	20	37-57
	0.516	3.6	21-52	25-55	17-49	5-32	17-34	9-17	38-150
	0.39	0.2-1.7	22	28	16	-	-	16	67
	0.44	1-4.5	15-25	18-38	13-26	2-5	1-15	13	-
	0.104	3.6	50-67	54-70	48-49	33-51	34-59	2-8	38-150
Dairy	1.7	0.9-1.9	8-12	-	-	-	-	12-15	35-103
	0.841	1-1.8	12-13	-	-	-	-	18-19	15-76
	0.6	1.0-1.7	10-16	-	-	-	-	12	14-54
	1.7	1.6	12	-	-	-	-	15	40-114
	0.841	1.6	6	-	7	-	-	16	38-108
	0.6	1.6-3.2	1-16		5-7			15-16	19-63
	0.841	6.8	26	-	-	-	-	24	71
Rotating									
Swine	0.75	2.5-4.12	4-8		4			16-17	80-307
	0.8	1-4.5	5-24	9-31	2-19	5-11	3-9	12	-
Belt Press									
Swine	0.1	3-8	47-59	-	39-40	32-35	18-21	14-18	
Centrifuge									
Swine	-	1-7.5	15-61	18-65	7.8-44	3.4-32	58-68	16-27	-
Beef	-	3.6-6.2	51-61	60-65	52-60	23-28	43-48	19-26	-

Source: Zhang and Westerman 1997.

The removal of solids, P, and other suspended or dissolved constituents can be improved by adding chemicals to the influent of solids removal processes.

. . . aeration... remove[s] organic material or oxygen demand...[and] a portion of the N and P by biological uptake... .

or cleaned out. Biosolids or sludge from a sedimentation tank or clarifier must be handled in a manner similar to solids removed by other processes. In an SBR, both aeration and sedimentation occur in the same unit on a sequential time basis.

Flocculation

The removal of solids, P, and other suspended or dissolved constituents can be improved by adding chemicals to the influent of solids removal processes. The chemicals or flocculation agents commonly used for municipal wastewater treatment include alum and lime as well as a range of polymers currently being developed. It is especially important to add the minimum amount of chemicals possible and to obtain good contact with all of the wastewater to maximize efficiency and minimize the amount of sludge. New equipment is being developed that effectively adds the minimum amount of polymer because it is expensive and results in large amounts of sludge that must be managed. If lime is used, then the resulting sludge has enhanced agronomic value.

Aeration

In a municipal treatment process, aeration commonly follows initial solid separation to remove organic material or oxygen demand, which is often referred to as BOD or COD. Aerobic treatment can also remove a portion of the N and P by biological uptake, but the composition of microorganisms, which is about 50% C, 10% N, and less than 1% P, limits N and P removal. Therefore, in aerobic treatment, about 50% of the C is converted to sludge or biomass that is removed in a sedimentation tank following aerobic treatment. Activated sludge, a commonly used form of aerobic treatment, returns the sludge or biomass to the inflow portion of the aeration basin, providing a high level of acclimated biosolids or biomass in conjunction with a high rate of aeration to rapidly convert nutrients to cell mass. Trickling filters are also used to aerobically treat wastewater by uniformly applying it to a rock filter where biomass grows. When growths become too thick, the biomass is sheared off the rocks and removed in a subsequent settling tank.

Many different types of bubble or surface aerators can provide aeration. The aerators can be used in existing or new lagoons to reduce odor and ammonia volatilization by converting ammonia to nitrate, which subsequently becomes N gas by denitrification in anaerobic zones or subsequent anaerobic units. By selecting appropriate surface aeration equipment or by placing air defusers above the bottom sludge zone, aeration can be designed to mix the total lagoon or only above the sludge zone. When aeration is limited to the lagoon surface liquid, the bottom, or sludge zone, remains anaerobic. Thus, the benefits of anaerobic decomposition of solids can be obtained and the upper portion may be aerated to reduce odor and ammonia volatilization at a reduced energy input. In lagoons without complete or high-rate aeration, it is important to provide sufficient aeration, so that ammonia volatilization or stripping is reduced rather than increased.

Anaerobic digestion

Anaerobic digestion takes place naturally at ambient temperatures under anaerobic liquid or soil conditions such as landfills or animal waste lagoons. Anaerobic digesters have been used at municipal wastewater treatment plants to reduce the sludge generated by aerobic treatment. The most commonly used anaerobic digestion units are mesophyllic which operate at about 95°F. The operation of these digesters is relatively routine; they produce a gas with about 60% methane and 40% carbon dioxide. This gas can be used as a fuel for gas combustion engines that drive generators, producing electricity and hot water. Thermophyllic digesters, which operate at about 165°F, are also used because the rate of gas production is significantly increased, offsetting increased heating requirements. However, the operation of thermophyllic digesters is more demanding because the optimum temperature range is very small and biological upsets are more frequent. In conclusion, the major benefits of anaerobic digestion are the (1) reduction of COD or BOD and solids and (2) production of methane gas, which has energy value. Anaerobic digestion does not reduce manure's N and P content, and thus the liquid and sludge effluent must be managed in a manner that handles or uses these nutrients. To avoid biological upsets and process failure, the maintenance, monitoring, and proper operation of anaerobic digesters are very important.

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Natural systems

Many treatment or runoff control systems are being developed that follow the basic principles of natural systems such as wetlands or riparian areas. Constructed wetland systems that can remove high levels of N have been developed for municipal and animal waste. If the wastewater is nitrified before wetland input, denitrification in the wetland system is significantly increased. Vegetative filter strips and riparian areas as well as overland flow plots or wetlands are being used to reduce the pollution potential of runoff or infiltration that may occur from an animal production/manure management system.

Many treatment or runoff control systems are being developed that follow the basic principles of natural systems such as wetlands or riparian areas.

Manure Utilization and Treatment Technologies

Land application

Land application, which is used as a terminal receiver for untreated manure and many treatment technologies, is discussed in detail in other curriculum lessons.

Byproduct recovery

Many systems are being developed that process the manure nutrients derived from separated solids and biomass or sludge into value-added byproducts. Raw and composted manure and mortalities have been processed to such value-added byproducts as fertilizer, animal feed, and crab bait.

Animal manure and mortalities can be mixed with other organic materials or waste products and processed by extruding, drying, and pelletizing prior to dry storage as a feed or fertilizer. For example, fermentation and preservation systems for converting poultry mortality mixed with sweet potato waste into value-added products are also being studied. Turkey litter is being processed to produce a cattle feed ingredient, and deep-stacked poultry litter processed to enhance its value as a cattle feed ingredient. Deep-stacked poultry litter is also being evaluated as a protein supplement for animal feed. Details on some of these byproduct recovery technologies and systems follow.

Many systems are being developed that process the manure nutrients derived from separated solids and biomass or sludge into value-added byproducts.

Composting

Composting is a natural aerobic process that stabilizes a variety of organic matter ranging from forest litter to horse and cattle manure. It is one

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The advantages of compost over fresh manure are the reduced odor, fly attraction, pathogen and weed seed concentration, and ...better plant response due to the addition of stabilized organic material that builds better soil tilth.

of the major recycling processes by which materials return to the soil in the form of nutrients available for future use.

More recently, engineered systems that convert manure from livestock and poultry into compost have become popular. Some of this popularity has been based on the concept of converting manure from a financial liability into a value-added marketable product. Examples abound in which compost is being produced from manure and other waste materials at a profit, but other examples can be cited in which compost production and marketing have not been successful enough to justify costs. In Korea, swine manure that does not exceed the maximum allowed moisture content is composted at a large cooperative facility without additions. A large rotor revolves and travels through a bin-like structure to aerate and continuously move the compost from the input section to the output section where the compost is bagged. Marketing of the bags with colored representations of plants that would benefit from this composted product has been successful.

Benefits. When animal manure is composted, the available organic matter is stabilized to the extent that it is no longer readily decomposable and no longer subject to further anaerobic decomposition with its associated odors. Well-composted animal manure has the odor of humus and is most acceptable for land application in locations where fresh manure would be objectionable. Volume reduction ranges from 25% to 50%, depending upon the initial material. Because of the heat produced during composting, well-controlled composting results in the destruction of both pathogens and weed seeds. If dead animals are used, some ingredients, such as feathers, teeth, and bone fragments that resist composting, may be removed by mechanical screening if necessary.

The extent to which N is conserved in the composting process depends largely on the carbon-to-nitrogen (C:N) ratio in the feed material. If the feed has a C:N ratio of 30 or above, little N loss occurs. If the ratio is less than 30:1, as is the case if manure is the principal ingredient, ammonia release tends to raise the ratio. If the ratio is 20:1, N losses can be as high as 40%. Carbon-to-nitrogen ratios above 30:1 generally result in nearly complete N conservation that may require a longer time to reach completion because the N is a limiting nutrient.

Composting is most frequently adopted by livestock producers who have a market for the finished product. That market may be nearby garden or nursery supply outlets, landscaping services, or contractors establishing lawns or landscaping after a construction project has been completed. Cities frequently use compost to establish and maintain parks and other recreational areas. The advantages of compost over fresh manure are the reduced odor, fly attraction, pathogen and weed seed concentration, and according to many horticultural studies, a better plant response due to the addition of stabilized organic material that builds better soil tilth. The disadvantages are the additional processing cost and the need to remove and manage a large amount of solids in the manure management system. Thus, like other alternative or advanced treatment technologies, composting is not compatible with all livestock operations. A thorough analysis of the advantages and disadvantages for an individual site is important.

Temperature. Aerobic fermentation releases a considerable amount of heat during the composting process. The composting material retains this heat, and elevated temperatures result. However, high temperatures are essential for the destruction of pathogenic organisms and weed seeds. Decomposition also proceeds more rapidly in the thermophyllic range than at lower temperatures. The optimum temperature is around 60ºC (140ºF).

Moisture content. Moisture is necessary for microorganism growth, but excessive moisture displaces the air that is necessary for microorganism growth. The ideal moisture content for composting is between 40% and 60%; the upper limit somewhat depends upon the material being composted. If the material contains straw, it may be possible to operate successfully well above 60% moisture, because straw retains its strength at higher moisture contents and still allows air to freely move through the pile. Waste paper, in contrast, becomes very soggy at 60% moisture and packed with sufficient density to exclude air. Thus, a compost pile containing waste newsprint needs to have a lower moisture content.

Aeration and turning. Aeration is necessary during thermophyllic aerobic digestion in order to produce a high-quality compost and to avoid nuisance conditions during composting. Aeration can also be used to overcome an initial moisture content that is too high.

If a compost pile becomes anaerobic as indicated by odors or by a temperature drop during the first 7 to 10 days, then turning is required. No matter how anaerobic a compost pile may become, frequent turning and aeration will handle the situation.

Inocula. Throughout the history of engineered composting processes, the development and marketing of inocula and enzymes to aid the composting process have steadily increased. If the initial waste materials to be composted were sterile, a scientific basis would exist to support the addition of microorganisms. Since that is clearly not the case with manure composting and because composting processes throughout the world operate successfully without microbial or enzyme additions, it must be concluded that inocula or other additives are not essential in the composting of waste materials, including animal manures.

Vermicomposting

Vermicomposting is a process where earthworms and microorganisms convert organic materials into nutrient-rich humus called vermicompost. The resulting vermicompost can be used as a soil amendment similar to conventional compost.

Removing the solids from a waste stream before a lagoon for vermicomposting or composting reduces lagoon loading and thus the potential of odor and ammonia volatilization. It also reduces the amount of land required to apply the lagoon liquid. Nutrients and organics diverted from the lagoon are stabilized by the vermicomposting process, making it easier to find off-farm uses for the product.

Methods for growing earthworms range from extremely simple techniques such as boxes and outdoor windrows to complex automatic systems with continuous flow reactors, overhead gantries, and automatic collection of castings or metabolic byproducts. In all of these systems, fresh organic manure is frequently applied to the surface of the worm beds where the worms concentrate. The fresh manure must be carefully added to maintain aerobic conditions and avoid excessive moisture. Following the vermicomposting process, the worms are separated from the castings or compost product. The worms are needed for the vermicomposting process and have high value for animal and aquaculture feed.

Vermicomposting is a process where earthworms and microorganisms convert organic materials into nutrient-rich humus called vermicompost.

Alternative or advanced techniques for converting manure to energy result in the conservation of valuable manure constituents and reduction of odor and ammonia volatilization.

As animal agriculture becomes increasingly integrated with more large-scale production units in geographically concentrated areas, animal protein byproduct recovery and utilization will become a higher priority.

Vermicomposting of dewatered swine manure is currently being conducted on a farm in North Carolina that uses the manure solids recovered from a solid separator. The manure solids are applied to worm beds that are maintained in an enclosed greenhouse facility. After a period of processing, the final product is odor free and has excellent physical properties for use as a plant growth medium. The vermicompost product is quite consistent throughout the year because the composition of the manure does not change during the year and greenhouse use eliminates extreme environmental fluctuations.

Energy conservation

Alternative or advanced techniques for converting manure to energy result in the conservation of valuable manure constituents and reduction of odor and ammonia volatilization. The direct combustion of dry manure as a fuel source for a small electric generator could be an alternative. Anaerobic digestion has been used with beef, dairy, swine, and poultry manures to produce methane gas, which farm owners may use to produce electricity for on-farm use or sale to an electric utility. The resulting hot water also has energy value. The last section provides a case study that discusses a covered, in-ground anaerobic digester for waste treatment and energy recovery.

Animal protein byproduct recovery

As animal agriculture becomes increasingly integrated with more large-scale production units in geographically concentrated areas, animal protein byproduct recovery and utilization will become a higher priority. These animal byproducts are rich in C, N, P, and minerals. Environmental and public health regulations, economic scenarios, and technology availability are the main forces that govern the utilization of these byproducts. To solve present and future problems with animal agriculture byproduct utilization, technology research and development must be a priority. However, the social issues that accompany these technologies must always be considered.

Mortality utilization

The proper disposal of mortality continues to challenge the livestock and poultry industries because of its implications for bio-security and public health, environmental safety, and public relations. Many of the current disposal options potentially risk environmental safety, contribute to groundwater and surface water contamination, cause odors and pests at disposal sites, and increase the risk of spreading pathogenic organisms.

The waste generated from normal poultry and swine farm mortalities is substantial. Normally, about 100 pounds of mortality is generated per 1,000 broilers raised to market and 500 pounds of mortality per 1,000 turkeys raised to market. Although these mortality mass figures are low, a broiler or turkey grower must commonly dispose of over 10 tons of mortality per flock each year. Considering all of the poultry produced in the United States, about 650,000 tons of poultry mortality must be managed per year. The swine industry must also manage an enormous amount of mortality carcasses because the annual mortality mass generated per sow is about 40 pounds. When the national production of swine is considered, over 180,000 tons of dead pigs must be managed in the United States. Using this waste product to produce value-added byproducts is an excellent alternative to other waste degradation treatment processes.

Recycling mortality carcasses as feed nutrients offers many advantages, such as recovering resources efficiently, minimizing nutrient emissions into the environment, and defraying waste treatment costs. Preventing spoilage and controlling pathogenic organisms by stabilizing waste products through direct acidification/pickling has been used as an alternative to fermentation for many years. On-farm preservation methods such as freezing, lactic acid fermentation, or acidification with phosphoric acid increase the storage potential of mortality carcasses, thereby reducing the transportation costs, by up to 90%, associated with daily pickup and transfer to a recycling facility. However, the high-energy costs, capacity limitations of freezer operations, and technical difficulties associated with biological fermentation have limited the acceptance of these technologies. The recent successful utilization of feed-grade phosphoric acid and equipment to preserve mortality has renewed interest in on-farm mortality preservation and storage technology. Widespread implementation of this automated technology is expected to significantly increase the proportion of mortality carcasses that are stabilized on the farm by direct acidification, and therefore, are available for conversion into feed nutrients.

Recycling mortality carcasses as feed nutrients offers many advantages, such as recovering resources efficiently, minimizing nutrient emissions into the environment, and defraying waste treatment costs.

Producing nursery potting materials from animal byproducts

The results from over 20 studies indicate that animal waste components can be beneficial additions to the nursery potting substrates used to grow ornamental crops. These components can substitute for nutritional additives such as dolomitic limestone and minor element supplements. In addition, animal waste components tend to increase P tissue levels in crops that are frequently deficient when grown in standard nursery potting substrates.

Animal waste components provide nutrients early in the growth stage and serve the role of starter fertilizers that growers frequently apply. On the other hand, use of these components requires careful management of both nutrient application and irrigation management. Overall, nursery managers who have successfully produced a wide variety of nursery crops with varied container substrates can also successfully grow nursery crops using animal waste components in the potting substrate and benefit considerably from their use.

...animal waste components can be beneficial additions to the nursery potting substrates used to grow ornamental crops.

Reducing phosphorus (P) excretion to improve fertilizer use options

Applying livestock and poultry manure to land at agronomic rates for P requires more land because of the much lower animal manure application rates allowed and the fact that P has accumulated in many soils over time. As discussed in the curriculum lessons on animal dietary strategies, animal nutritional strategies are being developed that reduce N and P excretion. These strategies may result in a manure with more agronomically balanced levels of N and P, greatly increasing its possible use as a fertilizer.

Reducing copper and zinc in swine and poultry diets to facilitate byproduct recovery

In recent years, soil zinc and copper concentrations have increased in some areas where swine and poultry manure have been applied, raising concerns about zinc and copper accumulation in soils to levels that reduce the production of certain crops. Therefore, high levels of copper and zinc in swine and poultry manure may restrict its use as a fertilizer and for other byproduct recovery processes. If zinc and copper intake is exceeded, relative

As a result of physical, biological, and chemical processes that take place in wetlands, many pollutants in the water flowing through the system are transformed or inactivated.

to the animal's requirement, the amount excreted in feces increases. Animal nutritional studies are being conducted to formulate diets in which the mineral levels are close to the mineral requirements, resulting in manures with increased potential for byproduct recovery.

Constructed wetland systems

Constructed wetlands simulate natural wetlands and have the same general components of landform, water, soil, plants, microbes, plant litter (also called organic matter, or detritus), and fauna. As a result of physical, biological, and chemical processes that take place in wetlands, many pollutants in the water flowing through the system are transformed or inactivated.

Wetland system experience. A literature review funded by the U.S. Environmental Protection Agency (EPA) and by EPA's Gulf of Mexico Program compiled information for 68 different sites using constructed wetlands to treat wastewater from concentrated animal feeding operations (CAFOs). Table 25-2 shows the average treatment performance.

Of the 68 sites identified, 46 were at dairy and cattle-feeding operations, 19 were at swine operations, one was a poultry operation, and two were aquaculture operations. The herd sizes of the dairy and cattle-feeding operations ranged from 25 to 330 head with an average of 85 head. Dairy wastewater often included wastewater from milking barns and from feeding/loafing yards with varying characteristics. Cattle wastewaters typically came from areas where animals were confined. Before being discharged to the constructed wetlands, dairy and cattle manure was usually pretreated or diluted. At the 19 swine operations, the swine manure was collected from solid floor barns and paved lots using flush water or directly from slatted floors in farrowing or nursery barns. In many cases, the wastewater was pretreated in lagoons or by solids separation.

Although the percent reductions shown in Table 25-2 are good, the average outflow concentrations are not consistently low enough to allow discharge into surface waters. Instead, the effluent is usually collected and land applied. Because the levels of N and P are reduced, however, less land is required to apply the effluent at agronomic rates.

Pretreatment requirements. The high level of organic C, N, and solids in animal manure usually requires pretreatment by lagoons or solids separators. Otherwise, the wetland system can be overloaded with (1) oxygen-demanding

Table 25-2. Literature data for 68 different constructed wetlands that treat wastewater from CAFOs.

Wastewater Constituent	Average Concentration, mg/l		Avg Reduction, %
	Inflow	Outflow	
5-day BOD	263	93	65
Total suspended solids	585	273	53
Ammonium N	122	64	48
Total N	254	148	42
Total P	24	14	42

Source: CH2M Hill and Payne Engineering 1996.

pollutants and N that cause wetland plants to die and (2) solids that build up at the wastewater inlet.

Types of constructed wetlands. Several types of constructed wetlands can be used to treat animal wastewater and feedlot runoff: surface flow, subsurface flow, reciprocating, and floating aquatic plant systems. In some cases, natural wetland systems are used for municipal treatment, but they are not considered to be constructed wetlands and cannot legally treat animal manure.

Surface flow constructed wetlands are the most commonly used wetlands for treating animal manure and the type that the USDA Natural Resources Conservation Service currently recommends in the technical requirements of the Constructed Wetlands for Agriculture for Wastewater Treatment. The advantages of surface flow wetlands include the (1) ability to efficiently treat the high-strength manure associated with the discharge from animal lagoons and other pretreatment facilities; (2) relatively low construction costs compared with subsurface systems; (3) relative ease of management; and (4) ease of repair and maintenance if problems occur.

Subsurface flow constructed wetlands contain below ground level gravel, rock, or soil media through which the wastewater passes in a horizontal direction. The wastewater level remains just below the surface elevation of the porous bed. Subsurface flow wetlands have an advantage in cold climates because treatment occurs below the ground's surface and is thus somewhat insulated from the cold air. In addition, these wetlands have virtually no odors and mosquitoes. When properly designed, gravel-based subsurface flow wetlands efficiently remove biodegradable organic matter and nitrates from wastewater.

A major disadvantage of subsurface flow wetlands is the potential for plugging, which causes water to pond on the surface. The potential for plugging is much higher for livestock systems, which usually contain very high solids concentrations. In addition, the installation cost is typically at least five times more than it is for surface flow wetlands for the same area.

Reciprocating constructed wetlands recurrently fill and drain wetland cells, which promotes the sequential development of aerobic (unsaturated) zones and anaerobic (saturated) zones for nitrification and denitrification to remove N as N gas. The hydraulic retention time (HRT), frequency of reciprocation, reciprocation cycle time, and water depth are important operational parameters for system optimization. Although more expensive than lagoons or surface flow wetlands, reciprocating constructed wetlands may be the least-cost technology for simultaneously removing significant amounts of BOD, nutrients, and odor from pretreated wastewater.

Wetland summary. Overall, wetlands by themselves cannot consistently remove sufficient N and P to meet stream discharge requirements. They do show promise, however, for high N mass removal, meaning that much less land would be required for terminal application. Sequencing a nitrification pretreatment component before the wetlands can increase their N removal efficiency. Such systems could provide an alternative to anaerobic lagoons and still provide high levels of N removal with reduced ammonia volatilization and odor. As a result, much less land would be required for terminal application at agronomic N application rates. Preliminary studies indicate that only 10% to 15% ammonia volatilization occurs during summer conditions for constructed wetlands receiving lagoon liquid at the high N loading rate of 25 kg/ha/day.

. . .wetlands by themselves cannot consistently remove sufficient N and P to meet stream discharge requirements. They do show promise…for high N mass removal… .

EXAMPLE PROBLEM

For a 4,000-hog finishing operation, calculate the total land required for a constructed wetland loaded at 15 pounds of total N per acre per day for 270 days of operation per year and for the required terminal land irrigation area based upon a N loading rate of 150 pounds of total N per acre per year.

Calculate the total land required for a constructed wetland loaded at 25 pounds of total N per acre per day for 270 days of operation per year and for the required terminal land irrigation area for 400 pounds of total N per acre per year.

This comparison illustrates a conservative design with minimal ammonia volatilization from a constructed wetland at a low N loading rate and low level of N fertilization with a high constructed wetland loading rate that may result in ammonia volatilization and a high N fertilization rate that may result in increased groundwater nitrate levels. These results can also be compared with land requirements determined by agronomic rates for P.

Nitrification is becoming an increasingly important component of total farm management systems for N conservation or removal.

Nitrification and denitrification alternatives

Nitrification is becoming an increasingly important component of total farm management systems for N conservation or removal. Nitrifiers oxidize ammonia to nitrite and then to nitrate N, which is a nonvolative form of N for fertilization. Once in a nitrate form, the transformation to N gas (or denitrification process) requires a source of C and an anaerobic environment. Such conditions are typically found in wetlands, lagoons, or liquid manure storage units.

Nitrifying bacteria compete poorly with heterotrophic microorganisms, particularly in manure treatment systems with high C or organic levels. Nitrifiers need oxygen, lower organic C, and a surface area for growth before sufficient numbers are present for effective nitrification. The results from three studies of nitrification are presented as case studies.

List of alternative utilization and treatment strategies

Information on the following alternative technologies can be obtained at the following North Carolina State University (NCSU) website: <http://www.cals.ncsu.edu/waste_mgt/apwmc/reactivities.html>

- Biofilter for Removing Odorous Compounds in Exhaust from Swine Buildings
- The Chemistry and Behavior of Phosphorus in Heavily Manured Soils
- Compositing as a Suitable Technique for Managing Swine Mortalities
- Conversion of Ensiled Poultry, Fish, and Sweet Potato By-Products into High-Value Poultry and Aquaculture Feed Ingredients
- Deep-Stacked Broiler Litter as a Protein Supplement for Dairy Replacement Heifers
- Developing Laboratory Techniques to Predict Nitrogen Release from Organic Wastes

- Development and Demonstration of a Fermentation: Preservation System for Converting Poultry
- Mortality and Sweet Potatoes Into Added-Value Products
- Evaluation of Alternative Constructed Wetland Systems for Swine Wastewater Treatment
- Evaluation of Fluidized-Bed Drying Technology for Recycling Poultry Litter as Bedding Material
- Evaluation of Wetland Plant Species for Use in Constructed Wetlands
- Genetically Engineered Microorganisms for Utilization of Ammonia and Other Nitrogenous Compounds from Animal Manure
- Grass and Riparian Buffer Treatment of Runoff from Land Receiving Animal Waste
- The Long-term Nutritional Value of Wastes for Crop Production
- Management of Animal Wastes in Support of Sustainable Agriculture and Quality of Water Resources
- Maximum Nonhazardous Soil Phosphorus Concentrations from Applications of Poultry House Litter
- Molecular Phylogenotic Survey of Methane-Producing Archaea in Animal-Waste Sludge
- Nitrogen Loss from Intensively Grazed Pastures Receiving Swine Lagoon Effluent
- Optimizing the Proteolytic Degradation of Animal By-products
- Optimizing the Use of Livestock and Poultry Manures as a Co-Substrate and Source of Inorganic Nutrients for the Biodegration of Hazardous Compounds
- The Potential of Thermophilic Anaerobic Fermentation of Biological Methane Production and Odor Control Using Swine Manure as Substrate: A Laboratory Evaluation
- Predicting Nutrient Release From Food and Animal Waste Products
- Production of Amino Acids and Peptides from Feathers and Other Proteniaceous Wastes Using Immobilized Keratinase
- Recovery of Solids from Flushed Swine Manure for Utilization
- Separation of Turkey Litter to Enhance Its Value as a Cattle Feed Ingredient
- A System for Development of Value-Added Products from Swine Manure and Peanut Shells
- The Use of Poultry Litter as a Co-substrate and Source of Inorganic Nutrients and Microorganisms for the ex situ Biodegradation of Petroleum Compounds
- Utilizing By-Products to Clean Air in Swine Buildings

The NCSU Animal and Poultry Waste Management Center continues to evaluate alternative treatment systems. A reference for project updates is given in Appendix A.

Tables comparing alternative treatment technology processes on the basis of constituent removal, constituent conservation, gaseous affluent, and cost are presented in Appendix B.

Producers with an existing system or selecting and implementing a new system can refer to the assessment tool contained in Appendix C. This tool will help them select a manure treatment system or alternative that meets their livestock and poultry production/manure management needs.

19 Alternative Treatment Technologies Case Studies

One of the initial goals was to determine if the constructed wetlands system could produce an effluent that would meet stream discharge requirements.

1 Constructed Wetlands for Swine Wastewater

This study was undertaken to investigate the capacity of constructed wetlands planted with either native wetland plants or water-tolerant agronomic plants to treat swine wastewater from a lagoon. One of the initial goals was to determine if the constructed wetlands system could produce an effluent that would meet stream discharge requirements. Three sets of two, 3.5-meter (m) x 33.5-m wetland cells were constructed adjacent to the existing lagoon in 1992.

During the first year, the nitrogen (N) loading rate of 3 Kg/ha/day specified for advanced treatment for stream discharge was used, but effluent N and phosphorus (P) concentrations would not consistently meet stream discharge requirements. The goal was then changed to determine the maximum possible removal of N and P.

The second year N loading rate of 8 kg/ha/day resulted in about an 87% removal of N or about 1,880 kg/ha/yr. The third year N loading rate of 15 kg/ha/day resulted in about 83% N removal or about 3,360 kg/ha/yr. The fourth year N loading rate of 25 kg/ha/day resulted in about an 87% N removal or about 5,870 kg/ha/yr. Mass removals are for 270 days of operation per year used to protect equipment from freezing. Mass removal efficiencies for these loading rates are shown in Table 25-3. The N loading rate for the fifth year was continued at 25 kg/ha/day to determine if the same removals could be achieved as during the previous year. Preliminary testing indicates only 10% to 15% ammonia volatilization for constructed wetlands receiving lagoon liquid at a high N loading of 25 kg/na/day.

Conjunctive microcosm studies were conducted to determine the maximum N loading rate possible and determine maximum N removal with sequencing nitrification and wetland treatment. Results show that with nitrification pretreatment, wetlands have the potential to remove more than 10,000 kg N/ha for 270 days of operation per year to protect from freezing.

Table 25-3. Nitrogen loading rates and mass removal efficiencies for constructed wetlands, Duplin Co, NC (June 1993-December 1998).

N Loading, kg/ha/yr	System	% Mass Removal[1]	Average Annual N Removal, kg/ha/yr	Average Effluent N Concentration, mg/l
3	Rush/bulrush Cattails/bureed	94 94	760	8.2
8	Rush/bulrush Cattails/bureed	88 86	1,880	24.2
15	Rush/Bulrush Cattail/Bureed	85 81	3,360	29.5
25	Rush/Bulrush Cattail/Bureed	90 84	5,870	46.0

[1] Mass Removal = % mass reduction of NH_3-N + NO_3-N in the effluent with respect to the nutrient mass inflow for 270 application days per year.

Conclusions. Wetlands by themselves cannot remove sufficient N and P to meet stream discharge requirements but do show promise for high rates of N mass removal with the result that much less land is required for terminal application. Placing a nitrification pretreatment component prior to the wetlands can increase the N removal efficiency of the wetlands. Such systems could provide an alternative to anaerobic lagoons and still provide high levels of N removal with reduced ammonia volatilization and odor with the result that much less land is required for terminal application. However if a lagoon is not used prior to the constructed wetland, an alternative solids removal technology is required to minimize solids deposition in the constructed wetland.

Wetlands...show promise for high rates of N mass removal... .

References

Rice, J.M., A.A. Szogi, F.J. Humenik, and P.G. Hunt. 2000. Long Term Data for Constructed Wetlands for Swine Wastewater. In Proceedings of the Third National Workshop on Constructed Wetlands/BMPs for Nutrient Reduction and Coastal Water Protection. NCSU, 24-26.

Stone, K.C., P.G. Hunt, A.A. Szogi, F.J. Humenik, and J.M. Rice. 2000. Constructed Wetland Design and Performance for Swine Lagoon Wastewater Treatment, ASAE paper #4148.

Rice, J.M., A.A. Szogi, Stephen Broome, Frank J. Humenik, and Patrick G. Hunt. 1998. Constructed Wetland System for Swine. In *Proceedings Volume I: Animal Production Systems and the Environment*. An international conference on odor, water quality, nutrient management and socioeconomic issues. Iowa State University, Ames, July.

2 Pilot-Scale Nitrification Prior to Constructed Wetland for Swine Waste

A five-year microcosm wetland study was conducted to assess the performance of sequencing nitrification and wetland treatments. Swine lagoon wastewater enriched with nitrate was applied to the microcosm wetland units at a rate of 190-kg nitrate-N/ha for a retention time of four days. About 80% of the nitrate applied were removed. On an annual basis, this removal potential is equivalent to about 14,000-kg N/ha, which is 5.4 times higher than the N removal without nitrification pretreatment. This indicates that the capacity of mass N removal by wetlands can be significantly increased by nitrification pretreatment.

Nitrification prior to wetlands can be provided by a media filter, encapsulated nitrifying bacteria, and overland flow. Data from field evaluation of these processes is presented in Case Study #3.

References

Rice, J.M., A.A. Szogi, F.J. Humenik, and P.G. Hunt. 2000. Long Term Data for Constructed Wetlands for Swine Wastewater. In Proceedings of: The Third National Workshop on Constructed Wetlands/BMPs for Nutrient Reduction and Coastal Water Protection, NCSU, 24-26.

Stone, K.C., P.G. Hunt, A.A. Szogi, F.J. Humenik, and J.M. Rice. 2000. Constructed Wetland Design and Performance for Swine Lagoon Wastewater Treatment, ASAE paper #4148.

In overland flow, nitrification occurs when a thin film of water is in close contact with a nitrifying population at the soil surface.

Lagoon wastewater was applied as a fine spray on the surface of the media filter....

3 Nitrification Alternatives

Nitrification alternatives evaluated include overland flow, media filter, and encapsulated nitrifiers. Typically, the lagoon liquid that served as the wastewater source contained 365 mgL^{-1} of total Kjeldahl nitrogen (N), mostly (> 95%) as ammonia-N, 93 mg L^{-1} of total phosphorus (P), 740mg/L^{-1} chemical oxygen (COD), and a pH of 8.2.

Overland flow. In overland flow, nitrification occurs when a thin film of water is in close contact with a nitrifying population at the soil surface. It also offers the advantage of partial denitrification in the underlying saturated soil layer. The treatment unit consisted of a 4-meter (m) x 20-m plot with a 2% slope. The sides and bottom of the unit were lined with plastic after excavation to a 20-cm depth and filled with the same sandy topsoil. Vegetation consisted of a mixture of fescue, coastal Bermuda grass, and reed canary grass. Lagoon liquid was applied five days a week with hydraulic rates of 2.5 to 3.0 cm/day. Preliminary tests showed that the sandy soil was highly permeable and that applying these hydraulic rates during 8-hour periods often failed to provide a surface runoff. Therefore, to obtain a functional surface flow, applications during the evaluation period (1996 and 1997) were only made during four hours each day. Hydraulic losses were similar to the expected evapotranspiration losses (0.5-0.8 cm/day).

Spatial sampling of the surface runoff water along the plot revealed that no nitrification activity occurred in the first 5 m of the plot. Beyond this point, the nitrate concentration gradually increased up to a maximum occurring at 17 m downslope. The nitrification rate also changed with time during the 4-hour application period. Highest activities were generally observed during the first two to three hours of application. Nitrogen budgets showed that losses of ammonia through volatilization were usually about 13%.

Performance data for the overland flow treatment are shown in Table 25-4. The higher application rate in 1997 reflects changes in lagoon N concentration. On a mass basis, average total N removal efficiency was 35% in 1996 and 42% in 1997, which is equivalent to 22.4 to 41.6 kg N/ha/day, respectively. The lower nitrate recovery values observed after treatment (Table 25-4) suggest that simultaneous denitrification occurred in the saturated soil layer, a typical feature of overland flow systems.

Media filter. The pilot unit evaluated consisted of a 1.5 m diameter x 0.6 m high tank filled with marl gravel. To avoid clogging by swine wastewater, gravel with a high calcium carbonate content that removes P was used instead of typical sand media. The distribution of the gravel particles was 85% in the 4.7-mm to 12.7-mm size class and 14% in the 12.7-mm to 19-mm size class, providing a pore space of 57%. Filtrate was collected for recirculation.

Lagoon wastewater was applied as a fine spray on the surface of the media filter at a hydraulic loading rate of 684 L/cubic meters (m^3) reactor volume/day. The corresponding average total N loading rate was 249 g N m^3 d^{-1}. The pilot unit was operated from March to July 1997, five days a week during 12-hour periods (6 a.m.-6 p.m.) under an intermittent flow mode to enhance aeration inside the media. The intermittent flow was controlled by a timer that turned a pump on and off at 12-minute intervals.

A six-week acclimation period was needed to develop a functional nitrifying biofilm on the media surface, indicated by stabilization of the nitrification activity. Unit performance was evaluated for 90 days after acclimation (Table 25-5). A lime supplement consisting of 100 g/day of crushed lime applied to the surface of the media filter during the second half

Table 25-4. Treatment of lagoon swine waste water with overland flow.

Year	Total N Application Rates, Kg/ha/day[1]	Evaluation Period, days	Total N Removal Efficiency, %[2]	NO_3-N Recovery, %[3]
1996	64	85	35	7
1997	99	60	42	7

[1] Total N = TKN + NO_3-N. (Inflow nitrate concentration = 0)
[2] Total N Efficiency = ([TN mass inflow - TN mass outflow]/ TN mass inflow) × 100
[3] NO_3-N Recovery = (NO_3-N mass outflow/TKN mass inflow) × 100.

of the evaluation period resulted in increased nitrification. The positive effect of lime may be due to increased inorganic carbon availability. As indicated by the total N balance, ammonia volatilization losses during treatment were small.

Encapsulated nitrifiers. The immobilization of microorganisms in polymer resins is a widely applied technique in drug manufacturing and food processing. This technique was recently applied to municipal wastewater treatment in Japan. The nitrifiers are entrapped in polymer pellets that are permeable to the ammonia, oxygen, and carbon dioxide that these microorganisms need. Swine lagoon wastewater was treated under continuous flow in a nitrification tank equipped with a screen to retain the pellets with the encapsulated nitrifiers and an aeration system to ensure appropriate fluidization of the pellets. This ensures that the desired amount of nitrifiers is maintained in an aerobic or oxidizing reactor. Pellets were added at 15% (w/v) pellet to total tank volume ratio.

Nitrogen loading rates were increased by gradually decreasing the HRT from 24 hours to 4 hours (Table 25-6). Nitrification efficiencies of more than 90% were obtained with total N loading rates lower than 438 g N m^{-3} d^{-1} and an HRT higher than 12 hours. Although higher loading rates resulted in lower treatment efficiencies, the total amount of nitrate produced was higher, with the maximum nitrate production rate obtained with an HRT of 4 hours. Higher efficiencies may be useful for total systems designed to meet stream discharge requirements. However, if the objective is to remove large amounts of N from operating lagoons on a periodic or continuing basis with a mobile unit, then a retrofit nitrification unit operated at shorter retention times is recommended. This strategy has the advantage of reducing the total cost of aeration per unit of nitrate-N produced.

Swine lagoon wastewater was treated under continuous flow in a nitrification tank equipped with a screen to retain the pellets with the encapsulated nitrifiers and an aeration system to ensure appropriate fluidization of the pellets.

Table 25-5. Treatment of lagoon swine wastewater with media filter for 90 days.

N Form	No Lime Inflow	Outflow	Lime Inflow	Outflow
TKN (mg L^{-1})	336	221	363	114
NH_4-N (mg L^{-1})	340	193	334	106
NO_3-N (mg L^{-1})	0	133	2	208
TN (mg L^{-1})	366	354	365	322
NE	26%	57%		

TN = Total N = TKN + NO_3-N.
NE = Nitrification efficiency = (NO_3-N conc. outflow/TN conc. inflow) × 100

Table 25-6. Treatment of lagoon swine wastewater with encapsulated nitrifiers.

HRT, hours	Total N Loading Rate[1]	Ammonia Removal Rate[2]	Nitrate Production Rate[3]	Nitrification Efficiency[4]
	g N/m³ reactor volume/day			
24	238	223	240	100
20	272	254	279	100
16	342	311	327	96
12	438	363	397	1
8	668	402	417	62
6	926	498	499	54
4	1,349	604	567	42

[1]Total N = TKN + NO_3-N. (Inflow nitrate concentration = 0)
[2]Ammonia removal rate = flow × (NH_4-N conc. inflow - NH_4-N conc. outflow)
[3]Nitrate production rate = flow × (NO_3-N conc. outflow)
[4]Nitrification efficiency = (NO_3-N conc. outflow/TN conc. inflow) × 1005.

Summary. Overland flow is a low-intensity system that can remove large amounts of N per unit area through nitrification and partial denitrification. Performance data showed N removal rates of 22 to 42 kg N/ha/day.

The media filter is a medium-intensity system that is popular for small waste generators. Nitrification efficiency was 57% at total N loading rates of 249 g/m³/day.

Nitrifying pellets technology is a high-intensity system using fluidized bioreactors designed for more rapid, efficient oxidation of NH_3. Nitrification efficiencies of 91% were obtained at total N loading rates of 438 g N/m³/day and 42% at 1,349 g N/m³/day.

Current research efforts focus on the development of integrated systems for sequencing nitrification and denitrification unit processes that provide reduction of ammonia volatilization and odor and high removals of total N.

Reference

Vanotti, Matias B., Ariel A. Szogi, Patrick G. Hunt, Frank J. Humenik, and J. Mark Rice. 1999. Nitrification Options for Swine Wastewater Treatment. In 1998 Proceedings: Volume II. An International Conference on Odor, Water Quality, Nutrient Management and Socioeconomic Issues, Iowa State University, Ames, 795-800.

Flushed swine manure is ...treated with chemicals to precipitate phosphorus (P) and solids in a tangential flow separation (TFS) system.

4 Tangential Flow Separator

Technology description. Flushed swine manure is pre-screened with a screening/conveying/dewatering unit (shaftless spiral screw, screening, and a flightless zone dewatering section) and subsequently treated with chemicals to precipitate phosphorus (P) and solids in a tangential flow separation (TFS) system. The system consisted of a lime slurry tank, a pre-floc mixing (reaction) tank, a TFS tank, a thickening tank and associated pumps and flow meters. Ferric chloride and polymer are injected into the flow after the pre-floc tank. The flow is then conveyed into the TFS tank at a tangent to the wall, settled solids accumulate at the bottom of the TFS unit, and finally flow into a thickening tank of similar design to the main unit. Supernatant is either recycled back to the TFS tank or discharged to a storage unit. Pretreated product streams are separated solids. Post-treated product streams are liquid effluent and biosolids. The study was conducted on a commercial farm in Southeastern North Carolina under loading conditions of approximately 20 gallons/minute.

Project results. Under the conditions tested, the pre-screening unit removed approximately 15% of the total solids and a much smaller percentage of the nutrients; the separated solids were 40% dry matter and 11% crude protein. Post-treated effluent showed P removal of more than 90% and copper and zinc removal of approximately 85%. Odor was not significantly reduced by the treatment system. With further processing, solids recovered from the TFS system may potentially be used as a soil amendment, potting media, or feed ingredient. Economic estimates of costs for a 3,600-head capacity finishing farm were as follows: initial investment of $140,000; annual operating costs of $15,000; potential revenue or other costs reduction of $15,000; resulting in net annual costs of approximately $2.60 per finished animal.

With further processing, solids recovered from the TFS system may potentially be used as a soil amendment, potting media, or feed ingredient.

Reference

http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999 report.html

5 Aerobic Biofilter Treatment of Flushed Manure and Stabilization of Screened Solids

Technology description. The technology provider was Ekokan, Inc. Innovative Biotechnology Processes. A pilot plant with capacity to treat up to 8 cubic meters (m^3)/day was installed in May 1997 at the North Carolina State University Lake Wheeler Road Field Laboratory, Swine Educational Unit.

The main system was composed of two upflow biofilters connected in series, three blowers, and two polishing tanks, also connected in series. The biofilters had a total volume of 1.76 m^3. They were packed with plastic media with a specific surface area varying between 115 and 165 m^2/m^3. An inclined screen and a filter press were periodically used to obtain solids for extrusion and characterization.

Flushed wastes from a swine research unit with a population of about 325 sows, 25 boars, 350 nursery pigs, and 500 finishing pigs were collected into a 26.5 m^3 concrete settling basin. A small portion of the overflow from the settling basin was pumped into a 4.2 m^3 storage tank. Waste was pumped from the storage tank to the first biofilter and traveled upward inside the biofilter. The partially treated effluent exited into a pipe at the top, and gravity fed to the second biofilter. The treated effluent from the second biofilter exited from a pipe at the top and was allowed to settle in two tanks connected in series. The clarified effluent was discharged back to the settling basin.

The biofilters were aerated using three blowers (one for each biofilter and a third for air scouring during backwash) (Aerzen GM 3S, Aerzen Canada, Inc.) with a capacity of about 1.2 m^3/min @ 1,900 rpm and 400 mbar pressure. The capacity of the blowers exceeded the aeration requirements, so about 0.2 m^3/min flowed to each biofilter and about 1.0 m^3/min was bypassed (discharged directly to the atmosphere). Air was diffused through perforated pipes located at the bottom of the biofilters. A design criterion was to supply air at 25 m^3 of air per m^2 of biofilter cross-sectional area per hour. Dissolved oxygen was normally between 6 and 8 mg/l in effluent from each biofilter but ranged from about 4 to 11 mg/l.

The biofilters were backwashed periodically by agitating with increased airflow so that the accumulated suspended solids and newly produced biomass were removed from the system. Typically, the backwash frequency was four times per day for the first biofilter and once every two days for the second biofilter. For the backwash cycle, about 25 cm of liquid depth was removed from the biofilter (from the bottom) to prevent overflow during the increased airflow. Then, air from all three blowers was diverted to the biofilter for 3 minutes. The more concentrated liquid was removed from the bottom of the biofilter. About 25% of the biofilter water volume (75 cm of liquid depth) was removed during backwash and stored in a tank where solids settled as biosolids. The upper liquid portion of the backwash was discharged back into the settling basin. For some tests, part of the biosolids that settled in the storage tank was dewatered in a drying bed. The remaining biosolids were discharged back to the settling basin.

Project results. The loading rate of the biofilters was based on chemical oxygen demand (COD) and was about 6 kg COD/m^3-day to the first biofilter, except during September 1997 when a higher loading rate of about 9.6 kg/m^3-d was used to test the biofilter's limits. The hydraulic flow rates to the first biofilter were normally 4 to 5 m^3/day.

Using liquid influent and effluent samples, an odor panel determined that two upflow aerated biofilters in series were able to significantly reduce odor intensity and irritation. Backwash from the biofilters had a higher odor intensity and irritation than did the effluent.

...the reduction in [biofilter] concentrations from influent to effluent was 72% for COD, 57% for volatile solids, 76% for SS, 72% for TKN, 82% for NH_3-N, 49% for total N, and 26% for total P.

With an average loading of 6.6 kg COD day per m^3 of media for 12 months, the reduction in concentrations from influent to effluent was 72% for COD, 57% for volatile solids, 76% for SS, 72% for TKN, 82% for NH_3-N, 49% for total N, and 26% for total P. Temperature affected the reductions, with higher reductions at higher temperatures. Most of the reduction in concentrations occurred in the first biofilter, but the second biofilter still had significant reductions as a percentage of influent concentrations to the second biofilter. During low temperatures, the first biofilter had very little nitrification, demonstrating some advantage for having the two biofilters in series for nitrification at low temperature. The COD mass removal rate was linear with a loading rate ranging from about 2 to 12 kg COD/day per m^3 of filter.

By calculating a mass balance over the period of monitoring, it was determined that about 30% of the influent volume, 35% of the total N, and 60% of the total P was removed with the backwash from the biofilters. Potentially, the backwash could further settle and concentrate the biosolids. In any case, management and utilization of the backwash is an important consideration when implementing this type of system on farms.

Another potential result of having an aerobic treatment system that converts organic and ammonia N to nitrate is that denitrification could occur when effluent is recycled to the swine buildings for pit recharge.

Brief Project Summary

Technology description. Aerobic treatment of pre-screened flushed liquid manure for purposes of reducing COD, odor, and ammonia volatilization (by promoting nitrification) was accomplished by two upflow, fixed-media biofilters connected in a series. Plastic fixed-media within the biofilters provides surface area for a biofilm of bacteria to aerobically stabilize organic matter and convert ammonia to nitrate. Pretreated product streams are separated solids. Post-treated product streams are liquid effluent and biosolids. The study was conducted at the North Carolina State University Lake Wheeler Road Field Laboratory (Swine Education Unit) on a pilot-scale system to treat waste from the equivalent of approximately 20 finishing swine from a flush system with a flow capacity of 2,100 gallons/day.

Project results. Under the conditions tested, the treatment system was able to reduce COD by 70%, total N by 50% with organic loading up to 6.6 kg COD/m^3-day. Reductions were higher in summer as compared to winter. Ammonia was nearly completely removed and converted to nitrates and nitrites. Full denitrification to environmentally inert di-N gas would be possible by adding a carbon substrate under anaerobic conditions or perhaps by simply recycling the treated effluent to flush the swine buildings and having an adequate retention time. Odor was significantly reduced by the treatment system. Phosphorus was not efficiently removed by the system; laboratory results indicated that P could be removed from the treated effluent with the addition of a chemical coagulant. Economic estimates of costs for a 4,000-head capacity finishing farm were as follows: initial investment of \$110,635; annual operating costs of \$25,274 (mostly for electricity); potential revenue or other cost reduction of \$16,360; resulting in net annual costs of approximately \$2 per finished animal.

References

Bicudo, H., A. Kantardjieff, and P.W. Westerman. 1998. Fixed Media Biofilter Treatment of Flushed Swine Manure. ASAE paper No. 984121.

http:www.cals.ncsu.edu/waste_mgt/apwmc/te.html

6 Nitrification/Denitrification

The technology provider was Triangle Environmental, Inc. (National Environmental Technologies, Inc.), and the evaluation site was Carroll's Foods, Inc. Farm 2539.

Preliminary results

- The nitrification/denitrification process startup was not successful during winter (Dec/Jan) with high loading (manure from 6,480 finishing pigs).
- The nitrification/denitrification process startup was successful within two weeks during summer (end of July) with moderate loading (manure from 2,880 finishing pigs).
- The treatment system has shown good stability with relatively few operational problems after the foaming was reduced and the liner was weighted to prevent floating.
- Based on flows and concentrations, the estimated nitrogen (N) reduction by the treatment system during September and October was about 85%. Effluent N is > 90% organic, < 1% ammonia, and about 5% nitrate N.
- Biomass accumulation in the treatment pond results in relatively high suspended solids (about 10,000 mg/L), high organic N (about 400 mg/L), and high total P (about 600 mg/L). Biomass was "wasted" on October 27 (about 120,000 gal.).

The nitrification/ denitrification process startup was not successful during winter… .

Collected biogas is utilized to power a[n]...electricity generator.

Additional information is needed regarding
- Ability to process higher loading rates.
- Performance during winter conditions.
- Volume of discharged manure annually and changes during storage (odor, N).
- Management and maintenance requirements over long periods.

Reference

http://www.cals.ncsu.edu/waste_mgt/Field_Day_1.html

7 Covered, In-Ground Anaerobic Digester with Energy Recovery

Technology description. A 20 ft deep, 1.35 million cubic feet (ft^3) volume, anaerobic digester lagoon is covered with a modular (four section) 20 mil high-density polyethylene. Collected biogas is utilized to power a 120-kWh electricity generator. Waste heat collected from the engine radiator is utilized to heat water in a 10,000-gallon water tank that provides heat, as needed, to the farrowing houses. Effluent from the covered digester is conveyed to a non-covered secondary treatment and storage lagoon, 2.05 million ft^3 capacity, and recycled for flushing of the on-site buildings and seasonally irrigated onto Bermuda grass to remove excess nutrients. The study is being conducted on a commercial 4,000 sow, farrow-to-wean swine farm in Johnston County, North Carolina.

Project results. Significant reductions of chemical oxygen demand (COD), total solids (TS), volatile solids (VS), and pathogenic bacteria have been measured in the covered anaerobic digester. Nutrient concentrations in the secondary lagoon are approximately 40% to 60% that of a typical single-cell lagoon. Thus, less land application area is required for subsequent nutrient removal. Odor analyses have shown that odor emission from the secondary lagoon is much less than that from a typical single-cell lagoon. Biogas production from the covered lagoon is approximately 800 ft^3 per hour during the winter and approximately 1,200 ft^3 per hour during the summer. Methane content of the biogas is approximately 72%. Waste heat collected from the engine radiator has been used to heat the water in a 10,000-gallon water tank, and the hot water has been providing heat to the farrowing houses.

The modular cover developed a leak and was replaced with a 40-mil HDPE bank-to-bank cover in July 1999. The new cover has performed well since then with the added benefit of eliminating rainwater from the covered digester.

Tables 25-7 and -8 summarize the performance of the covered, in-ground anaerobic digester.

There is a high removal of COD, TS, VS, and pathogens in the covered, in-ground anaerobic digester. The nutrient level in the storage lagoon is about 40% to 60% of that in a typical single-cell lagoon, which means that less land is needed for application at agronomic rates. Odor from the storage lagoon is less than that from a typical single-cell lagoon.

Biogas production from the covered, in-ground anaerobic digester ranges from about 800 ft^3 (or 23 m^3) per hour in the winter to 1,200 ft^3 (or 34 m^3) per hour in the summer with a consistent methane content of about 72%. The methane production co-efficient is about 0.3 m^3-CH_4 per kg VS degraded.

Table 25-7. Average nutrients, solids, COD, and pathogens in water at different stages of the covered digester treatment system.

	TKN, mg/1	NH_4-N, mg/1	Total P, mg/1	o-PO_4-P, mg/1	COD, mg/1	TS, %	VS, %	*T. coliforms,* mpn/100 ml	*E. coli,* mpn/100 ml
Raw wastewater	1,529	1,015	349	193	16,600	1.04	0.63	4.1×10^9	2.8×10^8
Digester effluent	979	837	98	93	1,060	0.26	0.08	5.0×10^6	1.7×10^6
Storage lagoon water	278	210	8	42	682	0.20	0.06	4.0×10^5	5.0×10^5

Table 25-8. Percent removal of nutrients, COD, solids, and pathogens in the covered digester system.

	TKN, %	NH_4-N, %	Total P, %	o-PO_4-P, %	COD, %	TS, %	VS, %	*T. coliforms,* %	*E. coli,* %
Covered digester	38	-	72	52	94	75	88	99.88	99.39
Storage lagoon	72	75	51	55	36	22	24	92	70.59
Overall	82	75	86	78	96	81	90	99.99	99.82

References

Cheng, J., K.F. Rous, and Leland M. Saele. 1999. Covered Anaerobic Lagoon System for Swine Waste Treatment and Energy Recovery. ASAE paper 9940489.

http://www.cals.ncsu.edu/waste_mgt/apnmc/reports/1999report.html

8 Vermicomposting

Technology description. It is well established that earthworms have an important role in the recycling of organic wastes and residues. They are utilized for the decomposition of the solid fraction of swine manure, and the end product is a fine particulate matter (castings) that is valuable as a plant growth medium. Swine manure is an excellent medium for the production of castings via vermicomposting; however, excess water from the flushed manure must be removed by a solids separation process. Methods for growing earthworms in manure in North Carolina range from simple methods such as boxes and outdoor windrows, to complex automated systems with continuous-flow reactors, overhead gantries, and automated collection of castings, all done in enclosed facilities.

Project results. More than 5 tons per week of swine manure solids is being vemicomposted at a farm in Wilson, North Carolina. Manure that has passed through an automated solid separator between the swine house and lagoon is placed on a 15 ft x 15 ft concrete pad. A front-end loader transports the manure to a 30 ft x 200 ft greenhouse, and a spreader delivers manure to 2 ft x 190 ft wooden worm beds, each of which holds thousands of pounds of red worms. Temperature and moisture are controlled with greenhouse curtains, shade cloths, fans, and an automatic mister. Castings are lifted and conveyed from the beds every other month by a retrofitted machine, and a harvester separates worms and eggs from the castings.

Greenhouse trials with ornamental and vegetable crops showed that plant

Methods for growing earth-worms in manure… range from simple methods such as boxes and outdoor windrows, to complex automated systems… .

performance was enhanced (increased blooming, larger plants, and increased root growth) when vermicompost was present in the range of 15% to 35% of the total growth medium; plant performance decreased when the proportion of vermicompost increased beyond this point. Fecal bacteria in the separated manure solids decreased rapidly following addition to the worm treatment beds. When compared to no-worm treatment controls, however, the die-off was not enhanced in the presence of worms. A laboratory evaluation showed that the odor reduction (decrease in odor concentration and irritation intensity) commonly observed in enclosed worm facilities is primarily due to the manure solids separation process and is not accelerated by the worms.

Castings are sold in 2-, 10-, and 25-lb bags marked Vermicycle: Nature's Ultimate Plant Food. Less than 8 hours per week are required to manage the operation.

References

http://www.cals.ncsu/waste-mgt
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

9 Sequencing Batch Reactor for the Treatment of Flushed Swine Manure

Technology description. A pilot plant with a capacity to treat up to 400 gpd (1.5 m^3/day) was installed in August 1997. The system is composed of a homogenization tank, a sequencing batch reactor (SBR), and biosolids and effluent storage tanks. The treatment system has been monitored since November 1997. Four different operational strategies are being tested.

An SBR is a fill-and-draw activated sludge treatment system. The unit processes involved in the SBR and conventional activated sludge systems are identical. Aeration and sedimentation/clarification are carried out in both systems. The main difference is that in conventional plants the processes are carried out simultaneously in separate tanks, while in SBR operations, the processes are carried out sequentially in the same tank.

In SBR operations, the cycle processes of fill, react, settle, draw, and idle are controlled by time to achieve the operation's objective. Each process is associated with particular reactor conditions (turbulent/quiescent, aerobic/anoxic) that promote selected changes in the chemical and physical nature of the wastewater. A complete cycle begins with the fill process, when flushed swine manure is added to the system, and ends with the draw process, when a treated effluent is removed from the system. To treat flushed swine manure, the operation may last between 12 to 24 hours. The heart of the SBR system is the control unit and the automatic switches and valves that sequence and time the different operations.

The SBR...can remove up to 93% of COD and 98% of SS...and... . NH_3-N can be almost completely removed and converted to nitrites and nitrates, which are then denitrified... .

Project results. The SBR, operated under an average temperature of 74°F (23.2°C), can remove up to 93% of COD and 98% of SS with a 24-hour cycle (HRT = 10 days) and short aerating/non-aerating periods. NH_3-N can be almost completely removed and converted to nitrites and nitrates, which are then denitrified under anoxic conditions; removal of fecal coliforms varied between 1 to 3 log units (90%-99.9%).

Long aerating/non-aerating periods resulted in high removal rates for chemical oxygen demand (COD) (89%), TSS (95%), and fecal coliforms (2-4 log units or 99%-99.99%), but lower removals of both nitrogen (N) (60%) and phosphorus (P) (15%). The system was able to nitrify (over 99% nitrification) but lost much of its denitrification potential. The longer aerating periods allowed nitrifying bacteria to fully develop and consume most of the available organic matter and alkalinity. Apparently an unbalanced microbial population developed within the biomass. The consumption of substrate and alkalinity by predominant species (mainly nitrifying and some heterotrophic bacteria) during aerating periods resulted in a severe drop of pH, probably cell lysis, and reactor failure.

At a lower hydraulic retention time (HRT) (5 day and 12-hour cycle) and short aerating/non-aerating periods, the SBR is still capable of removing a significant amount of organic matter, solids, and N (about 65%).

The SBR was able to remove between 40% and 70% of total P and Ortho-P, on average, during short aerating/non-aerating periods. Phosphates are probably being biologically removed from the incoming wastewater under cyclic anoxic/aerobic conditions inside the reactor. Under anoxic conditions, activated sludge releases large amounts of phosphate in the surrounding water. When the biomass is aerated again, the phosphates are absorbed by bacteria, which then can be removed from the system as biosolids. The rate of absorption of phosphate is greater than the rate of release, resulting in a net phosphate elimination from wastewater.

About 25% of the incoming wastes (vol.) are removed from the system as biosolids (between 0.9% and 1.0% TS). If the biosolids removed are allowed to settle into a storage tank, then a more concentrated material is obtained (about 2% TS). A clear supernatant is obtained after settling, and this is considered to be treated effluent. Its volume can account for at least half of the total volume of the biosolids originally withdrawn from the reactor.

Energy consumption was significant and may be attributed to an oversized blower for the pilot-scale system and the need to heat the reactor during winter months.

The SBR was able to remove between 40% and 70% of total P and Ortho-P on average, during short aerating/non-aeration periods.

Brief Project Summary

Technology description. Flushed swine manure is treated in the following sequence: (1) fill (containment vessel), (2) react (aeration that is cycled on and off), and (3) settle (remove solids for disposal). The system is designed to reduce organic carbon, convert ammonia to nitrate, and then convert nitrate to di-N gas, which can be released to the atmosphere safely; P can be removed through the bio-solids generated or by chemical precipitation. The technology has been used to treat wastewater from small communities for years. This study was conducted on a commercial farm in Halifax County, North Carolina.

Project results. Under treatment loading conditions of a 10-day HRT, COD, volatile solids, total N, and total P were reduced 93%, 75%, 95%, and 70%, respectively. Odor concentration intensity and odor irritation intensity were significantly reduced in both the treated effluent and bio-solids that the treatment system generated.

Under treatment loading conditions of a 10-day HRT, COD, volatile solids, total N, and total P were reduced 93%, 75%, 95%, and 70%, respectively.

References

http:www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html
http://www.cals.ncsu.edu/waste_mgt

Several technologies (polymer-enhanced solids separation, impeller aeration, and activated sludge treatment system with prescreening of solids) being used for municipal and industrial wastewater treatment are being tested as manure treatment alternatives.

10 Polymer-Enhanced Solids Separation

Technology description. A solids separator inclined belt press unit, equipped with a 1/16-inch screen polyacrylamide cationic polymer, was used to increase separation efficiency. The technology is designed to remove solids and associated nutrients from flushed waste before lagoon treatment. The study was conducted on a commercial 14,400-capacity, feeder-to-finish swine farm in Bladen County, North Carolina.

Project results. Under treatment conditions tested, which included utilization of the solids separator approximately 70% of the evaluation period, the test lagoon contained approximately 13% less total Kjeldahl N, 18% less ammonia-N, 12% less total P, and 16% less ortho-phosphate-P than a control lagoon receiving nontreated flushed manure. Biosolids depth in the treated lagoon was observed to accumulate more slowly in the test lagoon as compared to the control. Bench-scale analysis indicated that a 1/32-inch screen might be a more cost-efficient choice than the 1/16-inch screen.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.mcsu.edu/waste_mgt/apwmc/reports/1999report.html

11 Impeller Aeration

Technology description. Aeration (floating aerator designed to bring liquid from deeper in the lagoon to the surface) to retrofit existing lagoon for purposes of reducing lagoon solids volume, biological oxygen demand, odor, and ammonia volatilization (by promoting nitrification). The study was conducted on a 7,300-head, feeder-to-finish swine farm in Sampson County, North Carolina.

Project results. Under aeration conditions recommended by the technology supplier, nutrient concentrations in the test lagoon during the period of April 1997 through October 1998 were less than those observed during the same period of the previous year as follows: reductions of total Kjeldahl N 18%, ammonia-N 17%, total P 22%, and ortho-phosphate-P 19%. Electrical costs for the entire 19 months were approximately $340; capital costs for the aerator were approximately $2,000.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

12 Activated Sludge Treatment System with Prescreening of Solids

Technology description. Biological treatment with bacteria maintained on suspended solids. The components include an aeration basin, clarifier section with partial sludge return to aeration basin, storage for "wasted" sludge, recycle of effluent for flushing, and storage for excess effluent. The aeration basin is aerated with blown air to maintain a dissolved oxygen content of approximately 2 mg/L to promote aerobic stabilization of organic matter and conversion of nitrogen (N) to nitrate. Sludge with active bacteria is settled in the clarifier, a portion is recirculated to the aeration basin, and the rest is “wasted.” The nitrate in the effluent has potential to be denitrified to di-N gas by mixing with a carbon substrate under anoxic conditions. The pretreatment product stream is coarse separated solids. Post-treatment product streams are liquid effluent and “wasted” sludge or biosolids. The study was conducted at the North Carolina Department of Agriculture and Consumer Services Cherry Farm near Goldsboro, North Carolina.

Project results. The technology supplier designed the system for treating waste from a 315-sow, farrow-to-feeder operation. Organic loading was underestimated and resulted in inadequate aeration capacity, inadequate retention time, and inadequate clarifier size. The equalization (collection) pit was also too small and resulted in overflow of flushed wastes bypassing the treatment system. System performance was variable throughout a 12-month evaluation period. Biological oxygen demand was reduced by 35% to 55%, and some brief periods of denitrification were observed. The overall mass loss of N in the system was approximately 20%, and it is likely that this was due to ammonia volatilization. Dissolved oxygen was frequently less than 1 mg/L. Settling of solids in the clarifiers was also variable, and treated effluent generally had suspended solids concentrations of approximately 7,000 mg/L. The system required a certified Class II waste treatment operator and generally one person for 4 hours/day maintenance, monitoring, and operation. Numerous problems were encountered with pumps and blowers. Odor analysis (two sampling events) showed no statistically significant treatment effect on one day and significant improvement on the other day; however, odor intensity was still evaluated to be moderately strong. Economic estimates of the partial costs for this operation were as follows: initial investment of approximately $100,000 and electricity for energy use was variable from 300 to 500 kWh/day, which at $0.09/kWh would be $9,600 to $16,400/year.

Note that activated sludge treatment is a proven technology for municipal and industrial organic waste treatment for waste stabilization, N reduction, and odor reduction. It requires proper design, trained operators, and is energy intensive.

...activated sludge treatment is a proven technology for municipal and industrial organic waste treatment for waste stabilization, N reduction, and odor reduction.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.ncsu.edu/waste_mgtapwmc/reports/1999report.html

13 Dewatering/Bio-plate Composting

Technology description. Swine manure dewatering was accomplished by a screw press and sidehill separator. Composting of the resulting solids, which were mixed with wood chips, was enhanced by an in-vessel, aerated, static pile bin system using bio-plates for efficient air distribution. The objective was to reduce nutrient lagoon loading via pre-loading solids separation and to generate a viable stabilized product from the separated solids. The study was conducted on a commercial facility near Plymouth, North Carolina.

Project results. The side hill screen was determined to be more efficient and economical than the screw press for dewatering. Finished compost was of “exceptional quality,” meeting all state and federal regulations. Compost use

The side hill screen was...more efficient and economical than the screw press for dewatering.

as a supplemental component in media for ornamental and greenhouse crops showed that swine manure compost can be substituted for up to 75% of the currently used media. Rates of swine compost use depend on the soluble salts level in the compost and the plant species to be grown.

References

http://www.cals.ncsu.edu/waste_mgt
http:www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

14 Vacuum Microbubble Aeration

Technology description. Aeration to retrofit existing lagoon for purposes of reducing lagoon solids volume, biological oxygen demand, odor, and ammonia volatilization (by promoting nitrification). The study was conducted on a 250-sow, farrow-to-wean farm in the North Carolina coastal plain.

Project results. Under aeration conditions recommended by the technology supplier, the technology did not have a statistically significant effect on the environmental parameters tested.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

15 Electric Reactor/Solids Separation

Technology description. Flushed swine manure, approximately 2% total solids, is pumped into an enclosed tube that is receiving pulsed electric current. The tube contains electrodes with voltage output; the liquid influent closes the circuit between the electrodes, creating an electrical discharge that reacts with the solids in the manure waste stream. After treatment in the electrical tube, the effluent is subjected to solids separation via an inclined screen. The solids are taken offsite and used for vermicomposting. The treated effluent is discharged to an existing lagoon on the site. The study is being conducted on a commercial swine farm in Sampson County, North Carolina.

Project results. The results, to date, have been inconclusive. Environmental parameters including chemical oxygen demand, nitrogen, phosphorus, copper and zinc, as well as indicators of pathogenic microorganisms and odor have been measured. The liquid manure loading rate to the system has been approximately 200 to 250 gallons/minute. Some data points have shown some reductions of the parameters noted; however, most results have not been consistent. Stabilization (low odor) of the treated solids is a consistent trend. Most of the environmental parameters, including odor, have been consistently favorable for the onsite lagoon receiving the treated liquid effluent. However, the system had been in operation on this site for some time before the evaluation study. Thus, it is unclear what impact the system had on the lagoon since no pretreatment baseline of data was established. The technology supplier has recommended that the influent loading rate be decreased to 80 gallons/minute.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

16 High-Temperature Anaerobic Digestion/Solids Composting

Technology description. Flushed manure from an egg layer operation is anaerobically digested in an enclosed tank digester operating under thermophilic conditions (approximately 50°C). The biogas produced is utilized for the production of electricity and sold to a power utility. Solids from the digester are combined with composted substrates and utilized for greenhouse crop production. The study is being conducted on a commercial egg layer farm near Princeton, North Carolina.

Project results. An anaerobic digester on the farm operating at a lower temperature was converted to a thermophilic unit through cooperation with an engineering services firm. A waste-handling building has been constructed consisting of 12 aerated static pile compost bins equipped with a regenerative blower system. Problems have been encountered with separation of solids from the digester effluent (due to fine particle size), and efforts are underway to address this issue. The aerated composting bins are fully operational; manures have been blended with various bulking materials and other waste products to evaluate this system. A high-nutrient compost has been produced, and plant growth analysis trials will begin shortly.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

17 Aerated Basin/Solids Reactor Cells

Technology description. Manure is flushed to an aerated basin called a “bioreactor.” Natural microorganisms are stimulated to assimilate low molecular weight compounds that can cause odors. Effluent then flows into one of two deep cells called “solids ecoreactors” where solids are recovered and dewatered. The two cells operate in parallel; as one is filling, the other is left to cure and harvest. In these cells, a soil amendment product is created. The solids ecoreactors are designed to be harvested at least yearly. Effluent from the second bioreactor can be further treated in a third bioreactor and then directed to a temporary water storage area until needed for field application. The study is being conducted on a commercial swine farm in Bladen County, North Carolina.

. . .solids ecoreactors are designed to be harvested at least yearly.

Project results. Data collection was initiated in January 1999. Mass inputs to the system and removal efficiencies were calculated using estimated flow rates based on pump capacities and time of operation. Removal efficiencies for chemical oxygen demand (COD) and total suspended solids (TSS) were 95% and 93%, respectively, for the system, not including the storage pond. The largest removals of COD and TSS occurred in the solids ecoreactor, although substantial removal also occurred in the first and second bioreactors. Nutrient removals observed were 53% for ammonia nitrogen (N), 69% for total Kjeldahl N, and 87% for total P. Preliminary data shows that little N, but substantial P is removed from the liquid effluent in the solids ecoreactor. Therefore, based on data to date, indications are that the soil amendment product does not appear to be the endpoint for most of the N removed in this system. Removal mechanisms for N and P are being further investigated.

"Bioreactor" and "solids ecoreactor" are trade terminologies assigned by the company that represents this system.

References

http://www.cals.ncsu.edu/waste_mgt/
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

18 Secondary Treatment of Wastewater Using Duckweed

Technology description. This project involves a technology supplier that has developed a system consisting of a primary anaerobic digestion unit, a duckweed production unit, and a duckweed feed production process. In this system design, the primary treatment unit is lined to prevent seepage and covered to allow collection of gases; methane is collected and used for heating and drying of the harvested duckweed. Ammonia is separated and returned to the effluent from the digestion unit. This effluent is conveyed to the duckweed production units, which have large surface areas and shallow depths. Duckweed covers the surface and converts the nutrients in the effluent to biomass. A portion of the duckweed is harvested daily, and effluent from this unit is used to dilute incoming water to maintain acceptable concentrations of organics and ammonia for optimum duckweed production. Excess water is irrigated onto cropland and should contain very low concentrations of N. Harvested duckweed is stored in tanks and then dried and pelletized for use as animal feed.

Duckweed covers the surface and converts the nutrients in the effluent to biomass.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

19 Permeable Lagoon Cover

A floating, permeable composite cover manufactured from recycled polyethylene chips topped with a geotextile layer containing zeolite particles was evaluated under both laboratory and field conditions. Under laboratory conditions, the cover essentially eliminated odor release and reduced ammonia emissions by approximately 80%. When installed on a one-acre swine lagoon in eastern North Carolina, the cover survived severe storms and allowed even intense rainfall to pass through without causing cover inundation. Under these field conditions, the cover reduced ammonia emissions by approximately 80%. Odor emissions measured twice during one month of the study were consistently low in concentration, and an analysis by a trained odor panel determined that the emissions were near neutral relative to quality. The surface of the cover

A floating, permeable composite cover... reduced ammonia emissions by approximately 80%.

quickly became covered with an algae population within two weeks of installation. This and other vegetative growth, however, had no discernible impact on the cover's performance.

Lagoon sampling showed that constituent concentrations did not vary between sampling locations, indicating that even with a cover in place there is sufficient mixing within the lagoon to cause essentially uniform concentrations of the soluble constituents. Over time, nitrogen (N) has increased in the covered lagoon, which results in N conservation and the production of a more agronomically balanced effluent in terms of relative N and phosphorus (P) concentrations for land application but more land is required to accommodate the increased N. The surface of the cover reached a daytime temperature in excess of 120°F, but this heat was not transferred to the water surface because of the insulating properties of the covered material. The cover reduced the diurnal temperature fluctuations of the water surface to less than 2°F. It also reduced the rate at which the lagoon surface cooled in the autumn compared to a similar uncovered lagoon, resulting in a longer period of elevated temperatures to support biological activity.

Over time, nitrogen (N) has increased in the covered lagoon, which results in N conservation and the production of a more agronomically balanced effluent in terms of relative N and phosphorous (P) concentrations for land application… .

References

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Miner, J.R., F.J. Humenik, J.M. Rice, Diana Rashash, C.M. Williams, Wayne Robarge, Bruce Harris, and Ron Sheffield. 2001. Evaluation of a permeable, 2-inch thick polyethylene foam lagoon cover. Waste Management Programs, College of Agriculture and Life Sciences, Project Report May.

APPENDIX A
North Carolina State University (NCSU) Animal and Poultry Waste Management Center

The NCSU Animal and Poultry Waste Management Center continues to evaluate alternative treatment systems. A description of the status and updated project results for each of the following technologies may be accessed under Alternative Animal Waste Management Technologies—A Status Report at the following website: <http://www.cals.ncsu.edu/waste_mgt>

Activated sludge treatment with prescreening of solids

Aerated basin/solids reactor cells

Aerobic upflow fixed media biofiltration/solids separation/solids coating

Constructed wetlands

Covered in-ground digester

Dewatering/bio-plate composting

Electric reactor solids separation

High-temperature anaerobic digestion/solids composting

Impeller aeration

Nitrification/denitrification

Polymer-enhanced solids separation

Secondary treatment of wastewater using duckweed (Project 1)

Secondary treatment of wastewater using duckweed (Project 2)

Sequencing batch reactor

Tangential flow separator

Vacuum microbubble aeration

Vermicomposting

APPENDIX B

Tables Comparing Alternative Manure Treatment Technologies

Each treatment technology or unit process must be evaluated individually on the basis of constituent removal, constituent conservation, gaseous effluent, and cost. New or adapted unit processes can be used in a variety of ways, but performance of the total treatment system implemented is the end goal. In general, the cost and performance of sequencing of unit processes into a total system varies and is not well known at present. Therefore, the performance and cost of individual unit processes or manure treatment components are described in Table 25B-1 to facilitate comparison of alternative treatment processes and the selection of those processes most likely to meet an individual manure management need.

Table values are based on unit process operation according to recommended practices such as location, sizing, loading, operation, and maintenance recommendations for lagoons. They are relative and may change depending on unit type and operation.

Table 25B-1. Constituent removals from liquid stream by various treatment units.

Treatment Unit	Organic Material	N	P	Heavy Metals	Pathogens
High-rate aeration	M+	M-	M-	No	M+
Low-rate aeration	M-	M-	M-	M-	M+
Lagoon with high-rate aeration retrofit	M+	M-	M-	No	M+
Lagoon with low-rate aeration, aerobic/anaerobic zones retrofit	M-	M+	M-	M-	M+
Solids removal, mechanical	M+	M-	M-	M-	M-
Solids removal, gravity	M+	M-	M-	M-	M-
Chemical precipitation	M+	M-	M+	M+	M-
Lagoon	M+	M+	M+	M+	M+
Lagoon with impermeable cover	M+	N	M+	M+	M+
Lagoon with permeable cover	M+	M-	M+	M+	M+
Anaerobic digester with gas collection	M+	No	No	No	M+
Aerobic biofilter	M+	M-	M-	M-	M+
Constructed wetlands	M+	M+	M-	M+	M+
Sequencing batch reactor	M+	M+	M+	M+	M+
Land application	M+	M+	M+	M+	M+

Key: M+ = Major removal
M- = Minor removal
No = Little or no removal

Table 25B-2. Gaseous effluent from various treatment units.

Treatment Unit	Effluent Gas CH_4	Effluent Gas NH_3	Effluent Gas H_2S	Odor	Cost Initial	Cost Operating	Full-Scale, On-Farm Testing
High-rate aeration	M-	M-	M-	M-	H	H	Yes
Low-rate aeration	S-	S-	S-	S-	I	I	Yes
Chemical precipitation	N	N	N	N	H	H	No
Solids removal, mechanical	M-	M-	M-	M-	H	I	Yes
Solids removal, gravity	M-	M-	M-	M-	I	L	Yes
Land application	S+	S+	S+	S+	I	I	Yes
Lagoon	M+	M+	M+	S+	L	L	Yes
Lagoon with permeable cover	M-	M-	M-	M-	H	L	Yes
Lagoon with impermeable cover	M-	M-	M-	M	I	L	Yes
Lagoon with high-rate aeration retrofit	M-	M-	M-	M-	H	H	Yes
Lagoon with low-rate aeration, aerobic/anaerobic zones retrofit	S-	S-	S-	S-	I	I	Yes
Aerobic biofilter	M-	M-	M-	M-	H	H	Yes
Anaerobic digester with gas utilization	M-	M-	M-	M-	H	H	Yes
Constructed wetlands	M-	M-	M-	M-	I	L	Yes
Sequencing batch reactor	M-	M-	M-	M-	H	H	No
Composting, aerated	M-	M-	M-	M-	I	I	Yes
Composting, unaerated	M-	M-	M-	M-	L	L	Yes
Vermicomposting	M-	M-	M-	M-	I	I	Yes

Gas: M+ = Major increase; S+ = Minor increase
M- = Major decrease; S- = Minor decrease
N = No effect

Cost: H = High
I = Intermediate
L = Low

Table 25B-3. Potential recovery/conservation of constituents during operation of various treatment units.

Treatment Unit	Organic Material	N	P	Heavy Metals
High-rate aeration				
Liquid stream	M -	M +	M -	M +
Solid stream	M +	M +	M +	M +
Lagoon with high-rate aeration retrofit				
Liquid stream	M -	M +	M -	M +
Solid stream	M +	M -	M +	M +
Low-rate aeration				
Liquid stream	M -	M -	M -	M -
Solid stream	M +	M -	M +	M +
Lagoon with low-rate aeration, aerobic/ anaerobic zones				
Liquid stream	M -	M -	M -	M -
Solid stream	M +	M -	M +	M +
Lagoon				
Liquid stream	M -	M -	M -	M -
Solid stream	M +	M -	M +	M +
Lagoon with cover				
Liquid stream	M -	M +	M +	M -
Solid stream	M +	M +	M +	M +
Solids removal, mechanical				
Liquid stream	M -	M -	M -	M -
Solid stream	M +	M +	M +	M +
Solids removal, gravity				
Liquid stream	M -	M -	M -	M -
Solid stream	M +	M +	M +	M +
Aerobic biofilter				
Liquid stream	M -	M +	M -	M -
Solid stream	M +	M -	M +	M +
Anaerobic digestor with gas collection				
Liquid stream	M -	M +	M +	M -
Solid stream	M+	M +	M +	M +
Sequencing batch reactor				
Liquid stream	M -	M -	M -	M -
Solid stream	M +	M -	M +	M +
Constructed wetland, liquid stream	M -	M -	M -	M -
Land application, liquid stream	M +	M +	M +	M +
Composting, aerated, solid stream	M +	M +	M +	M +
Composting, unaerated, solid stream	M +	M +	M +	M +
Vericomposting, solid stream	M +	M +	M +	M +

M + = Major potential
M - = Minor potential

APPENDIX C
Assessment Tools

The following assessment tools will determine livestock and poultry production/manure management needs and assist with the selection of a manure treatment system or alternative technology that meets the needs of a producer with an existing system or a producer selecting and implementing a new system. These tools provide actual experience in utilizing the information in the section on manure treatment options. These tools can also assist producers in complying with national needs and local regulations.

Table 25C-1. Needs assessment tool.

Do you have enough land to apply all manure at agronomic rates for each constituent?	
If the answer is **yes**, then answer the three questions on the right.	1. Describe the odor and dust control techniques used in the production unit. Are they sufficient or what additonal measures are needed? 2. Describe the odor control techniques for the manure management systems. Are they sufficient or what additional measures are needed? 3. Would a different utilization strategy or technology be more cost effective or desirable? Provide a comparative analysis.
If the answer is **no**, then answer the five questions on the right.	1. What effluent constituents must be reduced? 2. What technologies can be added to the existing system to reduce each or all of these constituents? 3. What new system could be more cost effective to reduce each or all of these constituents? 4. How will the selected modified or new system control odor? 5. Will you select a utilization or destructive treatment system and why?

Table 25C-2. Performance assessment tool.

Current System	**Technology Would Use**	**Why**
If you had to remove the following constituents with your current system, what technology would you use and why? 1. Organics 2. Oxygen demand 3. Nitrogen 4. Phosphorus 5. Heavy metals 6. Pathogens	1. ______ 2. ______ 3. ______ 4. ______ 5. ______ 6. ______	1. ______ 2. ______ 3. ______ 4. ______ 5. ______ 6. ______
New System	**Technology Would Use for Individual Removal**	**Technology Would Use for Total Removal**
If you installed a new system, what technologies would you use to remove the following constituents individually or in total? 1. Organics 2. Oxygen demand 3. Nitrogen 4. Phosphorus 5. Heavy metals 6. Pathogens	1. ______ 2. ______ 3. ______ 4. ______ 5. ______ 6. ______	______

About the Author

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Glossary

Aerobic treatment. In wastewater treatment, aeration provides oxygen to obtain stabilized or oxidized end products such as carbon dioxide, nitrate, and sulfate.

Ammonia volatilization. Waste breaks down to ammonia under anaerobic conditions, and this ammonia can become an atmospheric gas through ammonia volatilization.

Anaerobic digestion. Waste treatment under anaerobic conditions, resulting in reduced end products with the majority of the organics becoming carbon dioxide and methane.

Biofilters. Aerated biofilters are packed with honeycomb type media and have air bubbles that travel upward through the media, facilitating growth of microorganisms responsible for wastewater treatment.

Biochemical oxygen demand (BOD). The amount of oxygen required by bacteria while stabilizing organic matter that can serve as food and energy for the bacteria under aerobic conditions.

Carbon-to-nitrogen (C:N) ratio. This ratio determines the extent to which nitrogen is conserved in the composting process. Carbon-to-nitrogen ratios above 30:1 generally result in nearly complete nitrogen conservation, but with lower C:N ratios, nitrogen can be lost. For example, if the ratio is 20:1, nitrogen loses can be as high as 40%.

Chemical oxygen demand (COD). The amount of oxygen required to oxidize all constituents in waste under the action of strong oxidizing agents in acid conditions.

Composting. An aerobic biological process for stabilizing organic materials.

Hydraulic retention or residence time (HRT). Measures hydraulic loading compared to process loading.

Influent. Waste input to treatment process.

Mortality. Dead animals that must be managed, preferably in a way that produces value-added byproducts.

Nitrification. The oxidation of nitrogen to nitrate.

Pathogens. Microorganisms that may cause disease.

Sedimentation. The separation of solids from wastewater by gravity.

Sequencing batch reactor (SBR). Sequential wastewater aeration to produce nitrate and then a non-aeration period to convert nitrate to nitrogen gas.

Vermicomposting. A process whereby earthworms and microorganisms convert organic materials into nutrient-rich humus called vermicompost.

Wetland system. Constructed wetlands simulate natural wetlands and have the same general components of landform, water, soil, plants, microbes, plant litter, and fauna that results in physical, biological, and chemical stabilization of wastewater.

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(Page numbers highlighted in green are linked to corresponding text.)

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Click on road map to return to Contents.

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Livestock and Poultry Environmental Stewardship Curriculum: Lesson Organization

This curriculum consists of 27 lessons arranged into six modules. Please note that the current lesson is highlighted.

Module A. Introduction

1. Principles of Environmental Stewardship
2. Whole Farm Nutrient Planning

Module B. Animal Dietary Strategies

10. Reducing the Nutrient Excretion and Odor of Pigs Through Nutritional Means
11. Using Dietary and Management Strategies to Reduce the Nutrient Excretion of Poultry
12. Feeding Dairy Cows to Reduce Nutrient Excretion
13. Using Dietary Strategies to Reduce the Nutrient Excretion of Feedlot Cattle

Module C. Manure Storage and Treatment

20. Planning and Evaluation of Manure Storage
21. Sizing Manure Storage, Typical Nutrient Characteristics
22. Open Lot Runoff Management Options
23. Manure Storage Construction and Safety, New Facility Considerations
24. Operation and Maintenance of Manure Storage Facilities
25. **Manure Treatment Options**

Module D. Land Application and Nutrient Management

30. Soil Utilization of Manure
31. Manure Utilization Plans
32. Land Application Best Management Practices
33. Selecting Land Application Sites
34. Phosphorus Management for Agriculture and the Environment
35. Land Application Records and Sampling
36. Land Application Equipment

Module E. Outdoor Air Quality

40. Emission from Animal Production Systems
41. Emission Control Strategies for Building Sources
42. Controlling Dust and Odor from Open Lot Livestock Facilities
43. Emission Control Strategies for Manure Storage Facilities
44. Emission Control Strategies for Land Application

Module F. Related Issues

50. Emergency Action Plans
51. Mortality Management
52. Environmental Risk and Regulatory Assessment Workbook