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ODOR RESEARCH AND MANAGEMENT

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Controlling Odor From Pork Operations

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Next to profitability, reducing odors from pork operations is one of the major concerns among producers. Effective odor control begins by identifying its source and taking appropriate action in that area. Odor from swine operations comes from three major sources: Building and facilities, waste-handling/storage systems and land application of manure.

BUILDINGS AND FACILITIES

Odors from within swine facilities can come from several sources. Manure covered floors release odorous compounds (ammonia, hydrogen sulfide and volatile organic acids) as bacteria act on the organic material. Animals soiled with manure, urine, dust and debris emit intense odors as they dissipate body heat. Decomposing feed release odors directly into the air and add organic material to the waste system increasing the opportunity for odor during waste storage. Dust from feed, bedding, dried fecal material and the pigs themselves when released into the air carry gases and odors that are released to the outside air. Some steps to reduce odor from swine buildings are:

- Floors should be kept as clean and dry as possible. Prevent excess spillage from drinkers and make efforts to minimize feed loss to manure pits.
- Manure buildup should be flushed or scraped regularly.
- Ventilation in livestock buildings should be adequate to prevent a buildup of dust, gasses, moisture and heat. Avoid excessive crowding of animals which intensifies odor production.
- Interior building surfaces should be as smooth as possible to facilitate cleaning and reduce the number of areas where dust and debris may collect.
- Feed delivery systems should be modified to release as little dust as possible.

Some options being considered to control odors from swine buildings are:

- **BIO-FILTERING OF EXHAUST FAN AIR**

  Bio-filtration involves the passing air from exhaust fans through straw or some other organic medium that is used as a filter. Microorganisms on the filter oxidize the odor producing volatile organic compounds and gases from manure. Unlike a dust filter that fills up and must be cleaned, biofilters are a living ecosystem of microorganisms that continually feed on odorous gasses. To support this living ecosystem, a bio-filter needs a moisture content of 50% to 60% plus the correct oxygen level, temperature and food source to stay alive. Before a bio-filter is considered operational, a conditioning period of a few months may be required to allow the organisms which oxidize the organic acids to multiply and adapt to a new environment in the filter. The efficiency of a new bio-filter will be low at first but increase during the adaptation period. In one field report, efficiency of odor removal increased from approximately 60% initially to 97% as the filter matured.

The filter material must have sufficient porosity so that it does not produce a back pressure that interferes with fan function. A University of Minnesota Biosystems & Agricultural Engineering Department publication (Bio-filter Design Information, BAEU-18, June 1998) indicates that exhaust air should remain in the filter mass for 5 seconds to effectively remove odor where swine barns have deep pit manure storage. This time does not seem to change with type of material used as a biofilter.

Filtering air from multiple exhaust fans means developing a filter strip of approximately one foot depth along the length of the building into which all fans can discharge air. A July 1998 Pork-98 article projected that a bio-filter for a 700-sow farrow-to-wean unit would cost $.22 per piglet produced when the initial investment was amortized over three years. The material in the filter is projected to last three to six years. Dust in the building must be controlled or the filter will clog. Protecting the filter from rodents is also important.

- **OIL APPLICATION TO FEED AND AIR**

  Dust particles in swine barns absorb odorous gases which they can carry away from the facility in exhaust air. Controlling dust is one way to decrease odors escaping from swine buildings. Mixing approximately 3% liquid fat or oil into swine feeds can substantially decrease the airborne dust that comes from feeds. Another strategy being investigated at the University of Minnesota is to apply daily, a small amount of soybean oil evenly throughout nursery rooms, pens and alley ways using a hand held sprayer. Dosage levels are under investigation but generally begin with .12 oz/sq.ft. for several days followed by maintenance doses of .015 oz/sq.ft. Preliminary results show some reduction in dust concentration and lowering of odor level when oil treatment was used.

- **NON-THERMAL PLASMA**

  The objective of this method is to produce OH radicals, ozone molecules and oxygen and nitrogen that when reacting with odorous and toxic gases form swine manure are converted to non-odorous molecules. Research is currently being conducted to determine the effectiveness of non-thermal plasma as an odor control method for swine houses.

WASTE HANDLING/STORAGE SYSTEMS

Manure removal, collection and storage are potential odor sources. Odorous compounds that accumulate in the waste as a result of anaerobic decomposition of the waste are released during agitation and mixing of the manure slurry. Methods to reduce the release of the odorous compounds include the following points:

- Manure collection pits should be recharged, flushed or scraped frequently to decrease the opportunity for drying and bacterial action on organic matter.
- Pipes delivering waste to storage should where possible enter the bottom of the structure to minimize agitation of the liquid.
- Adequately ventilate manure pits.
- Outside collection and junction boxes, sump tanks and storage basins should be covered to minimize air contact with manure.

Some options being considered to control odors during waste storage are:

- **COVERS**

  Covering the slurry reduces odors by decreasing air contact with the liquid surface. Various organic materials (approximately 12 inches in depth) have been used as bio-covers that float on the surface of the liquid manure. One study showed that ammonia release decreased by about 80% (4.1 grams/ cubic meter/ day for an uncovered tank to .7 1 grams/ cubic meter/ day) when the tank was covered with straw. Another study indicated that bio-covers decreased odors by about 50%. During 1996-1998, Iowa State University conducted a state-wide odor control demonstration project that involved 58 livestock operations. When 80% of the liquid surface was covered by wheat straw, odor decreased by about 50% with a cost of $.25 to $1.00 per pig marketed. A concern with bio-covers is that they may cause pumpout difficulties and that a chopper pump may be required. Also, the cover must be re-established each time waste is removed.

  Plastic covers or sealed lids nearly eliminated odors from the waste structure. A report from the Iowa State project indicates that the covers were estimated to last 8 -10 years and cost $.35-.$45 per pig marketed.

- **ANAEROBIC DIGESTION**

  This system was popular during the 1970's as an alternate way of producing fuel. Manure organic matter digestion generates methane and carbon dioxide (bio-gas). A tank holds the waste for 7 to 25 days during which time microorganisms break down the waste material and produce bio-gas. The tank is used to maintain a favorable environment for microorganisms, usually at 95 degrees F. A slurry solid content of 10%-12% is desired to minimize the tank size needed. Daily loading of the digestor is desirable. Methane, after scrubbing all other gases, is often used as fuel for internal combustion engines to generate electricity because the gas can not easily be stored. The efficiency of converting energy from methane to electrical energy is about 15%-25%. Using methane to fuel a boiler or water heater increases efficiency to 70%. The estimated electricity that can be generated per 130 pound finisher pig is 0.2 kWh/day/animal and 2 kWh/day/animal per sow producing 16 pigs per year. Inexpensive fuel from traditional sources means that odor control is probably a primary reason for considereing this waste treatment method. The Iowa State demonstration project results say that the fixed cost per pig marketed is $5.00-$12.00 per pig marketed. The energy recovered from the system may cover variable costs. Odor reduction is very effective with this system but high maintenance and management are required and some supplemental heat is required.

- **AEROBIC DIGESTION**

  Aerobic digestion is a very effective way to reduce odors. Oxygen is provided to microorganisms in the waste through mechanical or natural aeration. Naturally aerated lagoons, mechanically aerated lagoons, oxidation ditches and composting are some anaerobic systems. Aerobic systems are often considered uneconomical for livestock operations, but the advantage of odor control, aeration may increase their popularity. Estimated costs from the Iowa State demonstration project are $1.50-3.00 per pig marketed for fixed cost and $1.20-$1.50 per pig marketed for variable (operating) cost. Considerable space, maintenance and energy are required for artificial oxygenation systems. Liquid storage requires large surface areas at shallow depths and sludge build-up is a concern.

- **SOLIDS SEPARATION**

Separating solids from liquids decreases the organic load going into liquid storage structures by 25% which reduces the potential for odor from those structures. Mechanical separations screen out larger solids by centrifugation and can remove up to 30% of the total solids and up to 25% of the biodegradable organics. Settling basins use gravity to remove up to 50% of the solids from liquid manure. Most swine manure solids settle within 10-15 minutes, but some settling continues for hours. Solids from gravity separation are wetter, are less stable and potentially can produce more odor than from mechanical separated units. A chopper agitator pump is used to remove the high-solids slurry or the basin is drained, the solids allowed to dry and removed by tractor loader. Both liquid and solid manure handling equipment are needed and management is critical. The Iowa State demonstration project summary shows the cost per pig marketed as $3.00. A covered settling basin system has been used at the UW-Arlington Swine Research and Teaching Center since 1984.

- **COMPOSTING**

Compost is formed when a mixture of organic materials, such as manure, bedding or yard wastes decompose in the presence of oxygen. This is a natural process that breaks organic matter into a stable humus-like material that can be used as a soil conditioner. The process conserves fertilizer nutrients, kills pathogens and weed seeds and produces a relatively dry uniform product. Aeration is accomplished through turning the material by hand or with a bucket loader, windrowing or via a drum mixer. The optimum moisture content for composting is 50%-60%. Excessive moisture reduces aeration. For optimum processing and conservation of nitrogen, the carbon:nitrogen ratio should be 30:1. Animal waste carbon:nitrogen ratio usually is 10:1 to 15:1 so carbon must be added, often as straw, wood chips, paper or leaves. Temperatures in the compost pile will reach 140 degrees F. After several weeks the temperature decreases, signaling that composting is complete. Composting requires some set-up costs, sufficient land for storing and mixing material and continued management. The Iowa State demonstration project summary lists composting costs per head marketed as $.20-$.40. Composting reduces odors but there is the possibility that some odor can occur.

- **ADDITIVES**

Additives can be grouped into one of several categories based upon their mechanism of action: bacterial and enzyme products, oxidizing agents and germicides, masking agents, counteractants, digestive deodorants, absorbents, feed additives and chemical deodorants. The Iowa State demonstration project report indicates variable effectiveness among pit additives and that their cost ranges from $.25 to $1.00 per pig marketed.

LAND APPLICATION OF MANURE

A 1985 report indicated that the most significant complaint about odor from swine manure by the public is during and after surface spreading to the land. Spreading manure on top of the soil either by tankers or irrigation can cause intense odors. High trajectory guns with small droplet size are the worst combination for odor. Decreasing pressure which increases droplet size can lessen odors.

- **MANURE INJECTION BELOW THE SOIL SURFACE**

  Manure injection into the soil is the most effective way to reduce odor during land application. Odor intensity from the surface application at 440 yards downwind was perceived to be equal to that from injection only 55 yards away according to a 1987 report. Manure should not be released on the surface if maximum odor control is to be achieved. Applying waste at too high of a rate for the conditions or not having injectors fully engaged in the soil at the beginning and ends of the field before turning on the flow increases odor risk when manure is injected. Cultivation after surface spreading of manure can limit the odors to some extent but will never provide as much reduction as injection because some manure will always remain on the surface.

  The Iowa demonstration project found soil injection of manure cost $.40- $.50 per pig marketed based on injection cost of $.003/ gal. The extra nutrients saved were believed to more than pay for the cost of injection.

- **TIMING OF MANURE APPLICATION**

  » Apply manure early in the morning or on cloudy days. Manure applied early in the morning (at dawn) reduces ammonia emissions according to a 1990 report. Since most of the emissions take place during the first few hours following spreading, the higher temperatures combined with strong solar radiation causes a fast drying process of the slurry in the field and more ammonia release.

  » Apply manure on days which the wind is blowing away from neighbors and dwellings. The plume width from a swine odor source was measured in an Iowa State University study and found to be no wider than the source. Positioning the disposal path relative to the wind direction is important.

  » Apply manure on weekdays when neighbors have a greater possibility of being away from their home.

The system or combination of odor control measures that are best for an operation depends on the facilities, management and economic conditions present. The discussion above is intended to provide an overview of options and practices that apply to the three major areas where odors originate.

Control of Odor Emissions *from* Animal Operations

A Report

from the

Board of Governors

of the

University of North Carolina

Prepared by:

Odor Control
Report Task Force

North Carolina
Agricultural
Research Service

College of Agriculture
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North Carolina
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Sept. 1, 1998

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Control of Odor Emissions
from
Animal Operations

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This report will be available after Sept. 1, 1998 at the World Wide Web site of North Carolina State University's Animal and Poultry Waste Management Center. The Web address is http://www.cals.ncsu.edu/waste_mgt/Control.htm

Control of Odor Emissions *from* Animal Operations

Introduction

Farms on which animals are raised often concentrate odors associated with the microbial degradation of manure and other by-products of the production of meat, milk and eggs. Odors can be a nuisance to neighbors of animal operations, and there is increasing concern about the potential health effects from emissions of odorous compounds. Most people, regardless of where they reside, desire a living environment free of animal manure odors.

As the number of livestock and poultry operations in North Carolina has grown during the past decade, odor-related issues have intensified. Most of the state's agricultural growth is attributed to the swine industry, which has a current inventory of approximately 10 million pigs. At the same time, the state has experienced significant growth in its human population. As people and pigs have come into proximity, odor emissions have increasingly become an issue, especially in locations where animal operations are near areas of public sensitivity, such as housing developments, shopping and non-agricultural business centers, schools and recreational facilities.

The importance of animal agriculture to North Carolina's economy is well established. However, there is little doubt that in certain geographic areas of the state the continued productivity, profitability and sustainability of animal production agriculture and its allied industries will be dependent upon cost-effective technologies and management practices to mitigate odors associated with concentrated livestock facilities. To address this issue, the North Carolina General Assembly in 1997 mandated, per House Bill 515, Part III, Section 3.2, that "the Board of Governors of The University of North Carolina shall present its final report and recommendations on economically feasible odor control technologies, as provided in Section 27.3 of chapter 18 of the 1995 Session Laws (1996 Second Extra Session), to the Environmental Review Commission and the Environmental Management Commission not later than 1 September 1998." This document was produced by the North Carolina Agricultural Research Service at North Carolina State University to meet this requirement.

The use of a brand name in this document does not constitute an endorsement by the North Carolina Agricultural Research Service.

How This Report Was Produced

This report was written by a task force assembled by the North Carolina Agricultural Research Service. Most of the members of this group, whose names appear on the cover of this document, are faculty members in the College of Agriculture and Life Sciences at North Carolina State University. Most are also actively involved in research related to odor and animal agriculture. We have tried in this report to present the most up-to-date information available on what we know about odor generated by farms that raise animals and various methods of managing odors. We have also developed a number of recommendations that apply specifically to North Carolina and how the state might deal with odor from animal agriculture. The next section of this report will focus on our recommendations. Then we'll discuss methods of measuring odor, an important element if our recommendations related to odor emission standards are to be implemented. We will also examine odor control technologies and discuss the pros and cons of various methods of controlling odor from farms. Finally, the report concludes with sections on the economics of odor management, health considerations associated with odor, and society's expectations and social consequences related to odor issues.

Recommendations

Odor Assessments

As a first step toward the development of a system that will help farmers deal with odors from animal operations and ensure long-term resolution of complaints of odor from farms, we recommend that the State of North Carolina implement an odor assessment or monitoring program as soon as possible. This effort should begin with swine farms but eventually be extended to farms on which other types of animals are raised and, perhaps, to other sources of rural nuisance odors such as landfills, sewage treatment plants, fields receiving municipal and industrial sludge and pulp and paper plants. Monitoring of these odor sources will allow us to distinguish between farm odors and those from other nearby sources. Such a program will not be easy or inexpensive to establish and implement. For this reason, it is recommended that the program be phased in over an extended period of time, prioritized by operation size and/or proximity to neighboring residences.

Our ability to make informed decisions regarding odor from farms is now hampered by a lack of knowledge of the relationship between odor at the farm property line and a long list of variables that are known to affect odor. Among these variables are type of operation, building design, ventilation method, animal numbers, animal diets, manure treatment system, lagoon loading, season, topography and management skill or effort. Information from an odor assessment program will enable the state to build a database that will help us understand these relationships better. A better understanding of the factors that affect odor is critical to the eventual development of odor standards and/or flexible setback requirements based on expected odor levels at the farm property line.

Assessments will help farmers determine if they need to take action to mitigate odor and where to focus odor control efforts. The program will also establish an odor record for each farm monitored. This approach is intended to address real odor concerns as well as to deter unfounded odor complaints by providing an objective record of odor levels. A central goal of the program should be to assist animal operations personnel to understand and to meet odor emission standards. For this reason, the North Carolina Department of Environment and Natural Resources should have responsibility for program implementation; however, the North Carolina Agricultural Research Service and North Carolina Cooperative Extension Service should assist the Department of Environment and Natural Resources as consultants as needed.

Performance Standards

We recommend the eventual development of requirements or performance standards that specify how much odor is acceptable from an odor source. It would seem that any attempt to regulate odor will be unsuccessful unless odor standards are established. The State of North Carolina must determine the level of odor that is acceptable and whether and how often it is permissible for this level to be exceeded at a specific location, such as a residence, church, business or at the property line of a farm.

If a measurable quantity that may be used as a standard is to be determined, it would also seem that an odor unit would have to be defined. Such units are usually based on the number of times an odorous air sample is diluted with air without odor until 50 percent of an odor panel, a group of people trained to detect odor, can still detect the odor. A standard might say, for example, that experiencing an offensive odor level of 3 odor units five percent of the time is acceptable. It must be understood that **there is no well accepted standard of this type at present,** although there have been attempts to establish standards.

It may be useful in considering standards for odor to look at how standards for water quality are determined. The typical approach to regulating groundwater quality is to determine a compliance distance, such as the property boundary, then determine a standard that must be met at the compliance distance. For example, a standard for groundwater quality might be 10 milligrams per liter for nitrate nitrogen. In other words, if the concentration of nitrate nitrogen exceeds 10 milligrams per liter of groundwater at the compliance distance, then nitrate-nitrogen discharge at the source must be reduced. The same approach could be used for odor regulation. However, it is a limitation of this approach that odor concentration and quality may be transient, depending upon wind direction, time of day and stability of the atmosphere, and changes in emission rates at the source. In addition, it is expensive to measure odor transported in air by collecting air samples and taking them to a lab to be evaluated by trained panelists using olfactory equipment.

This illustrates the challenge of effectively regulating odor, and why it is imperative that we develop a database of information on various odor parameters. This database will be necessary for the development of effective odor standards. The assessment effort we recommended earlier in this report will help us begin to collect some of this information.

As we acquire the knowledge necessary to develop appropriate odor performance standards for North Carolina farms, we believe we will also be able to formulate better recommendations for setback distances. North Carolina and several other states and foreign countries already use setback distance requirements to regulate odor. The setback distance is supposed to be sufficient to allow dilution of odors to acceptable levels. It is likely that the same information necessary to formulate performance standards may also be used to refine setback requirements. It should be possible to develop appropriate and perhaps different setback distances for different types of livestock and poultry farms. It may also be possible to vary setbacks depending on number of animals, type of animals, management practices on the farm, topography and wind patterns.

Odor Response Team

As we work toward the development of performance standards and refine setback requirements, we suggest that the State of North Carolina establish odor response teams that would be available to respond to odor complaints. This would be a separate program unrelated to the odor assessment effort described earlier. Initially, response team members could use just their noses or perhaps a scentometer (see following section on measuring odor for a discussion of the scentometer) to determine odor concentration in the area where a complaint was lodged. Input by a representative or representatives of the complaining party or parties and the farmer whose operation appears to be producing odor is suggested as a response team investigates a complaint. The response team approach is basically the approach being used to investigate complaints of odor from industrial sources. It would seem logical that odor response teams would be directed by the Division of Air Quality, North Carolina Department of Environment and Natural Resources. However, there might be other organizations already in place (county health departments, for example) that could play a role in this effort. Determining acceptable odor levels would be a challenge. This approach begs the question: What do we need in the way of controls or practices that will enable producers to meet an odor standard at the property boundary? However, this overall approach has the advantage of being complaint driven, which should focus attention on the most pressing odor problems. In the meantime, more information can be gathered on the extent of the problem, the appropriateness of present setback distances, and how variables such as type of farm, management practices, technology and other factors influence odor levels.

Measuring Odor

If we are to develop workable performance standards, we must have accurate, objective methods of measuring odor. Indeed, almost any action we may contemplate regarding odor requires accurate measurement of odor. A variety of odor measurement methods are available, while others are being developed. These methods are discussed in the following sections.

Olfactometry

Although much progress has been made in the area of developing instrumentation for measuring odor, olfactometry, which makes use of the human nose, is currently accepted as the most valid procedure for odor measurement. Olfactometry involves collecting odor samples (odorants are contained in a volume of air or adsorbed onto a media such as cotton fabric), presenting the samples to an odor panel (a group of people trained to detect odor), recording the panelists' responses, and analyzing the resulting data. Samples of odorous air can be collected in the field, then transported to an odor panel for off-site analysis. Or samples can be analyzed on site, eliminating the need for storage and transport. The odor-containing air is diluted with nonodorous air. The lowest concentration at which panel members can still detect an odor is called the detection threshold. An instrument called a dynamic olfactometer is used to dilute odorous air with nonodorous air.

Control of Odor Emissions
from
Animal Operations

Scentometer

The scentometer is a hand-held device that allows on-site sampling of odorous air. The air that a person using a scentometer smells reaches the sniffer's nose through two holes, one for odorous air and a second (equipped with a charcoal filter) for nonodorous air. A scentometer is equipped with multiple holes of varying sizes through which odorous air travels. The size of the hole through which nonodorous air travels remains the same. As the user changes the hole through which odorous air travels different dilutions are achieved. Typical dilutions for a six-hole scentometer are 2, 7, 15, 31, 170 and 350 parts of filtered, nonodorous air to one part odorous air. There are no standards for describing the various dilution to threshold levels, but one researcher has described 170 dilutions to threshold (D/T) as a very strong odor, 31 D/T as a moderate odor, 7 D/T as a significant odor and 2 D/T as a weak but noticeable odor.

It is difficult to avoid breathing odorous air before the scentometer is used, which can cause the user to experience odor fatigue. Odor fatigue occurs when a person is continually subjected to an odor. After a time, the odor will not be as apparent. Because of the danger of odor fatigue, use of a respirator mask to shield a scentometer user from odorous air is often recommended. The scentometer has a relatively limited number of dilution options and presently has no standard method to screen sniffers so that dilution to threshold readings can be routinely compared and evaluated statistically. Recent attempts to reduce individual bias have included using a second person to uncover the sampling holes so that the sniffer does not know which holes are open. A scentometer is, however, an economical on-site screening method to estimate the strength of odorous air.

Using a scentometer: a case study

An NC State University graduate student used a scentometer to measure dilutions to threshold at various locations on six swine farms. The farms were chosen to represent the different types of buildings and ventilation systems used on North Carolina swine farms. Two farms used tunnel ventilation; two used underfloor ventilation; and two used roof ventilation. Measurements were taken near the area where ventilation fans discharge, at various locations about 20 feet from buildings, on the banks of lagoons, and on four of the farms at the edge of fields where lagoon liquid was being sprayed.

Dilution to threshold averages were:

- At ventilation fans: 302;

- At various locations approximately 20 feet from buildings: 2.8;

- On the banks of lagoons: 1.61;

- At the edge of fields being sprayed with lagoon liquid: 0.42.

The measurements recorded around buildings, on the banks of lagoons, and at the edges of fields being sprayed with lagoon liquid were not statistically different. The near-fan discharge measurement was significantly greater than measurements at the other locations, an indication of higher odor concentration at the ventilation fans. This would be expected since the fan discharge represents a point source before dispersion and dilution of odor by the ambient air flow. The dilution to threshold readings in this study indicated that odor levels around buildings, lagoons and spray fields averaged less than 3 dilutions to threshold, with around buildings and around lagoons measurements varying widely. It should be noted that all of these dilution to threshold readings are on-farm and do not represent measurements at farm boundaries. Also, the air sniffing was done by one individual. The sources of odor need further evaluation in terms of odor emission rates (air flow rates multiplied by odor intensity) and how the various sources of odor may be dispersed and diluted by the ambient air flow in traveling to the property boundary.

The Electronic Nose

An electronic nose may eventually prove to be the convenient, objective, inexpensive, portable tool needed to measure odor in the field. Researchers at North Carolina State University have developed a working electronic nose, but there is still considerable work to be done before the kind of tool needed to enforce odor regulations is available.

An electronic nose employs sensors that respond to the various chemical compounds that make up an odorant. The sensors respond by producing changes in electrical resistance in direct proportion to the concentration of the odorant. NC State researchers have compared evaluations of odor from swine farms by a trained human odor panel with an analysis of the same odor by the electronic nose. In this way, the electronic nose was "trained" to recognize the odor from a swine farm. The researchers demonstrated that at least with regard to one data set (one odor experiment), the electronic nose can produce the same perceptions of odor intensity, odor irritation and odor pleasantness or unpleasantness as the human nose. However, if the electronic nose is to be considered a reliable method of measuring odor, the same training procedure must be carried out with additional data sets. This is a time consuming process. Human perceptions of odor from trained odor panels must be used to train the electronic nose under various conditions (at different times of year and under various weather conditions, for example). Moreover, the sensors used thus far are capable of detecting odor only from point sources such as a swine building or lagoon. Researchers are working to develop a next generation electronic nose with sensors that are 10 times as sensitive as the sensors used in the current model. It is thought that an electronic nose equipped with these more sensitive sensors would be capable of detecting odors from nonpoint sources such as at the boundary line of a swine farm.

Tracer Compounds as Odor Indicators

If a chemical compound or compounds can be associated with an odor and the compound can also be quantified using chromatography or other analytical techniques, then the presence of the compound may be used as an indicator of odor intensity. Measurement using this technique assumes a direct relationship between the target compound and odor intensity or dilution to threshold. There are several classes of compound that may be used for measurement at the emission point and used as an input for a mathematical dispersion model to estimate the dispersion of different odorants. Various compounds have properties that can be used to describe how a scent lingers and how quickly it disperses. These properties should be considered when choosing an appropriate indicator. However, there are a number of drawbacks to this method of measuring odor. Research has shown the relationship between compound and odor is highly variable depending on an animal's diet, management variables and the degree of treatment of wastewater. Different diets, management techniques or wastewater treatments can change the chemical composition of the odor of manure or wastewater. Furthermore, odors from different sources differ in chemical composition. A compound that is suitable for measuring odors from a swine building may not be suitable for measuring odors downwind from the anaerobic lagoon treating the waste from that building. Therefore, at the present time the use of a single compound, such as ammonia or hydrogen sulfide, for odor quantification is not recommended. Some research indicates, however, that groups or mixtures of certain compounds show potential for use as livestock odor indicators.

The Connection Between Dust and Odor

Dust on livestock farms affects odor measurement and control in several ways. Dust particles adsorb odorous compounds. As the dust particles are carried by the wind, so is odor.

Most of the dust generated on a farm comes from feed, fecal matter and, in the case of poultry, from feathers and litter. Dust also comes from animal skin, insects and other sources. Some of the dust particles, such as those from manure and feed, emit odorous compounds as a result of bacterial decomposition. Odorous dust can carry many times more molecules of some odor compounds than the same volume of air. Dust, in other words, concentrates odorous compounds. As a result, odorous dust can cause an intense odor sensation if particles settle in the nose on the olfactory organ (where the sense of smell begins).

An understanding of the role dust plays in concentrating and transporting odor is important if we are to develop economical methods of controlling odor because some methods of removing dust from the air are less expensive than methods of treating the air directly to remove gaseous odorous compounds. Measuring dust levels gives an idea of the extent to which dust is likely to be responsible for odor problems, and if dust control is likely to be helpful.

There are two methods of measuring dust. The mass of dust in the air (usually milligrams of dust per cubic meter of air) may be measured, or the number of dust particles in the air (particles per cubic foot or per milliliter of air) can be measured. In addition, it is important to know the size of dust particles. Particles smaller than a certain size -- called respirable particulates -- can be inhaled deeply into the lungs and cause lasting damage. The size of respirable particulates is generally considered to be 5 microns or less. Mass-based measurements and particle-counting methods have been developed to sort dust into size classes; for example, less than 0.5 microns, 0.5 to 1 microns, 1 to 2 microns, etc.

It is desirable to be able to use both types of measurement methods, and there are methods of relating particle counts to mass measurements, based on the assumed shape and makeup of the dust. Particle-counting methods are generally simpler. Mass-based methods usually involve pulling air through a device so dust settles on filters, which are then weighed in a laboratory. Most regulations involving dust levels are based on mass measurements rather than particle counts.

Dust may also be analyzed microscopically. Microscopic examination of dust from swine buildings has shown that the majority of the dust comes from feed. Fecal material is also a substantial source of dust. To be effective, dust control should reduce dust from the feeding system.

It is also possible to measure the amount of bacteria, endotoxin (toxic materials produced by bacteria), gases such as ammonia, and odorous compounds in dust. Chemical analysis has shown that dust from swine facilities can adsorb, concentrate and carry ammonia and various odorous compounds. Gas chromatography is generally used to identify compounds in gaseous air samples and is often used in conjunction with other odor measurement methods to determine which compounds are responsible for odors. Gas chromatography is also used to identify and quantify the odorous compounds carried on dust. It can be used to indicate which odor compounds originate from feed and from manure and which compounds are likely to be carried on dust or in the air.

Government agencies and scientific organizations have adopted standards for permissible levels of particulates, or dust. The Occupational Safety and Health Administration (OSHA) has established permissible exposure limits for total and respirable dust. Ambient, or outside, air must measure up to standards developed by the Environmental Protection Agency (EPA). The indoor air quality regulations are intended to protect human health in the workplace, while the ambient air quality standards are intended to control air pollution outdoors. Both types of standards can apply to animal facilities.

Prediction Models

Many models have been developed that will predict the extent to which pollutants and odors can be dispersed downwind of the source. Mathematical dispersion models are valuable tools for regulatory agencies. The models allow for the simulation (prediction) of the emission of pollutants for a new or proposed expansion of a manufacturing facility or power plant. Results of such predictive models can be used to assess whether the addition of pollutants to the atmosphere will cause excessive concentrations at the ground level and jeopardize the health of people living in that area. Regulatory agencies can deny an air quality permit on the basis of the results of a predictive dispersion model as a means of protecting public health and welfare.

Mathematical models generally perform many calculations using information such the strength or concentration of the pollutant or odor source, the location(s) of the release point(s), the topography of the land, and meteorological information, including wind speed, wind direction and the mixing height of the atmosphere. Wind direction, speed and mixing height of the atmosphere are the most important factors governing the dispersion of odors. High wind speed and a high mixing layer promote the dilution of an odor plume and readily reduce the detectable odor strength. Models can predict the dispersion of dust, chemicals that form acid rain, units of odor, and distances from a source to a safe level of pollutant dilution. Some very sophisticated models account for atmospheric chemical reactions. Several mathematical models have been applied to the dispersion of ammonia and dust from animal buildings.

Researchers at the University of Minnesota have used a modified Environmental Protection Agency dispersion model based on puff theory, the idea that wind is seldom constant but tends to blow in intermittent puffs. Puff models are thought to be more appropriate for predicting agricultural odors because odor moves as a series of puffs rather than flowing as a continuous stream. The commonly used Gaussian dispersion models are unable to account for this puff phenomenon and the corresponding peak concentrations. An experimental dispersion prediction was successfully validated with a panel of preselected, trained sniffers. Although there were some differences between the measured odor and the model predictions, the estimated odor concentrations by the puff model at different distances downwind from the odor sources were reasonably close to the numbers obtained by human sniffers.

Empirical models (based on experiments and observations) differ from mathematical dispersion models in that they use a number of factors that are determined by measurements rather than theory. Several empirical models used in Europe have been developed to predict without the difficulties of complex calculations the distance that an odor plume can travel. The following method is used in Germany to determine the distance from an odor source the odor can be detected. A group of at least five field investigators line up at various distances downwind of an odor source, then record the intensity of the perceived odor on a scale from 0 to 6. The team repeats this process for approximately three different distances, making observations at each location every 10 seconds for about 10 minutes. With this information, the odor plume can be mapped. The model has the advantage that no odor or pollutant measurement equipment is needed. The distance is calculated by what is actually perceived by the human nose.

Another empirical model has been developed and used in Austria that predicts the protection distance required to avoid an odor annoyance from a livestock facility. This method requires the facility to be assessed in terms of animal type, animal number, building type, feeding system, manure storage and treatment system, and the lay of the land where the farm is located. A system of points is used for each category. The points are used to arrive at a cumulative odor number. The odor number is used to determine a protection distance that can be read off a graph. Pollutant emission rate measurements are not necessary for use of this model. Some researchers believe this model can be applied to livestock farms in the U.S. and may form the basis for future regulations.

The Dutch have established standards for odors from industrial sources that use emission data and calculate iso-concentration lines, or odor contours, using a computer dispersion model. This approach depends very much on having good measurements of emission rates at the odor source, good topography and meteorological information and valid dispersion models. The Dutch have used this approach to a degree for livestock farms, then compared their model predictions to how people living in the area perceive odor. They have attempted to define odor units and the number of odor units emitted per pig.

Challenges Associated with Odor Control

Factors such as concentration, frequency, duration, character and perceived offensiveness determine whether an odor or emissions from a farm are considered a nuisance or a health problem. Indeed, whether smelling an odor is an involuntary act or not can affect whether the odor is considered a nuisance. At the same time, farm odors are often intermittent, which can make identification of the source difficult.

And farm odors sometimes result from barely detectable levels of odorant compounds.

Then there's the human nose. It would seem a safe assumption that no two human noses are alike. The human nose is extremely sensitive. We can recognize many odorants in the parts-per-billion or less range. Yet we don't all detect the same odors. And even when we can agree that an odor exists, we don't always agree on whether the odor is pleasant or unpleasant.

Research has shown that it may not be economically practical or feasible to eliminate nuisance odors from farms where animals are raised. Yet we also know from research that it is possible to manage odor from farms. The array of management practices used on a farm, both in raising animals and in treating waste, affect odor, and management practices, both animal production and waste management practices, can be adapted to manage odor. And there is technology available to farmers that will reduce the concentration of odor and/or improve odor quality. We'll look next at various methods of controlling odor, first from the animal production standpoint, then from the waste management standpoint.

Production Strategies to Mitigate Odor

Facility Planning and Building Design

Swine production and waste handling and treatment facilities should be planned as an integral system that reduces environmental impacts while promoting animal health and performance and worker safety. An orderly system for manure collection and storage or treatment reduces potential pockets of odor production. All surfaces on which manure may collect and on which animals are maintained should be as clean and dry as possible. Dirty, manure-covered animals promote accelerated bacterial growth and the production of gases that are quickly vaporized by animal body heat. Minimizing the floor surface area on which manure can accumulate reduces the gases and odors emitted from these surfaces.

Adequate ventilation is essential for gas and odor reduction, moisture removal and temperature control. Underfloor ventilation aids in drying slotted floor surfaces and reduces indoor gas and odor buildups. Exhaust fans and shutters should regularly be cleaned of dust. Building sidewall screens should periodically be cleaned of debris such as dust, cobwebs and vines to allow maximum warm season cross ventilation.

All components of the production and waste treatment system should be maintained and operated in good functional order. Accumulations of solid manure and wastewater should be removed from these systems expediently. Proper disposal of dead animals and good fly and rodent control programs are also essential. (See Appendix for information on management practices that mitigate odor.)

Facility Siting

Where swine facilities are located can play a significant role in whether odors become a nuisance. Swine facilities should be located as far as practical from residential developments, commercial enterprises, recreational areas or other prime areas for nonagricultural uses. A site may seem ideal with respect to transportation, feed supply, accessibility or land ownership, but may present challenges because of existing or proposed development. When possible, production facilities should be located near the center of a tract of land large enough to allow manure to be applied to the land at agronomic rates. Pollution control and waste treatment facilities should be located as far as practical from areas of high environmental sensitivity such as drainage ditches, streams or estuaries. Buildings in flat high water areas should be built on pads of earth fill excavated for the treatment/storage unit. Elevating buildings several feet above ground will direct surface drainage away from the building, allow good natural air circulation, and allow manure to flow by gravity to the lagoon without additional pumping and agitation.

Additional criteria that must be evaluated are included in the USDA-Natural Resources Conservation Service (NRCS) Form NC-CPA-17, Waste Management Facility Site Evaluation Plan.

Dietary Manipulations

There are some data in the scientific literature documenting the reduction of odor and nutrients in animal excreta or alteration of the microbial population in an animal's digestive tract as a result of manipulation of the diet or from adding specific odor-reducing materials to the diet. In general, this research has shown that nutrients such as nitrogen, phosphorus, copper and zinc can be reduced through dietary manipulation without impacting the growth performance and health of the animal. This alone is a positive impact on environmental parameters. Dietary manipulation has also been shown in some cases to reduce the odor concentration and offensiveness of freshly excreted manure. Although research has produced mixed results, it should be noted that after storage of manure under anaerobic conditions, the positive impact of dietary manipulation on odor may not persist. However, odor control through dietary manipulation holds much promise and may revolutionize animal feeding practices within the next few years.

Ventilation

Ventilation is the movement of air through a swine building to provide the animals with fresh air and to remove moisture and (in warm weather) animal heat. Good ventilation is crucial to maintaining a healthy environment. Ventilation also affects odor.

Ventilation can be provided naturally or mechanically. Natural ventilation uses wind through openings in the building walls and, in some cases, openings in the ridge of the building. Warm air rises and flows through the ridge openings. Mechanical ventilation employs fans mounted in the walls to move air through the building. The distinction between natural and mechanical ventilation is important because it affects the nature of odors and dust in the buildings; the way the odors are carried out of buildings; and the types of odor control methods that can be used. Both ventilation methods can be effective, and both have advantages and disadvantages.

Natural ventilation can be less costly than mechanical ventilation due to lower initial costs and the cost of electrical power to operate fans. However, the ventilation airflow cannot be moved through air cleaners due to the absence of ventilation fans. In hot weather natural ventilation requires a good wind environment; a high ventilation rate is needed to remove the heat produced by the animals as well as heat from outside the building that is conducted through the walls. In areas where tree lines are close to buildings or the buildings are very close together and when wind speeds are low, the wind flow through and around buildings may be too low for animal comfort, causing heat stress. Indoor mixing fans can help alleviate this problem by blowing air directly over the animals, but indoor fans do not move much air into and out of the building. In areas with relatively high prevailing wind speeds such as at the top of a hill without nearby trees, natural ventilation may prove effective. Naturally ventilated buildings must be cooled in hot weather, either by dripping or sprinkling water on the animals or evaporating water using fogging nozzles and high pressure pumps, but such cooling also requires air movement over the animals to be effective.

Animal stress, which can be caused by overheating the animals, is apparently related to odor production. Several professionals who advise swine producers regarding facility design and management have indicated that when animals are chronically stressed, their dunging patterns can be adversely affected, resulting in manure buildup on the indoor walls, floor and the animals. This can increase odor production compared to a clean building.

Mechanical ventilation guarantees sufficient airflow through the building in hot weather if the system is designed, operated and managed properly. Tunnel ventilation, which clusters fans at one end of a building and air inlets at the other end so that air flows through the building as through a wind tunnel, is a popular method of ventilating animal buildings. Tunnel ventilation can provide high air speeds over the animals and effective cooling in hot weather. However, tunnel ventilation may chill the animals if high air speeds occur with cool air temperatures, so a different system is needed in cool weather, and system controls to allow switching between methods are important. Tunnel ventilation provides a relatively small area where all the ventilation airflow exits the building, typically with fans across the end wall, so air cleaning or odor-control systems can be placed at this location. However, fans used in swine buildings are seldom as powerful as those used in industrial or commercial buildings, so many industrial odor control systems will not work in swine buildings without installing more powerful fans. As a result, there are a limited number of odor control devices applicable to tunnel-ventilated animal buildings without greatly increasing fan and electric costs.

Underfloor Ventilation

Underfloor or pit ventilation is yet another method that may reduce odor. Building ventilation air enters the animal space from the outdoors, is pulled through the slats on which animals stand and into the airspace above manure liquid. The air is then moved out of the building by a manure pit fan. Due to the high airflow resistance caused by this airflow path, manure pit fans have to work harder than other building ventilation fans to move a given amount of air. However, this method can reduce or eliminate the flow of odors and gases such as ammonia from the manure pit into the animal space, which benefits animal and worker health. Underfloor ventilation by itself does not reduce the flow of odors out of a building, but by moving the most odorous air out of the building through the manure pit fans, underfloor ventilation may improve the effectiveness of systems such as biofilters or wet scrubbers. Several researchers have successfully reduced odors from manure pit fans with biofilters.

Airflow rate across the slats must be limited so that pigs will not be chilled during cold weather. As a result, underfloor ventilation does not provide the high airflow needed to cool the animals in warm weather. But in many cases it does provide the minimum ventilation rate needed in cool weather. Most swine buildings built in North Carolina over the past several years do not use underfloor ventilation because it can substantially increase the cost of buildings. It is possible to design retrofit underfloor ventilation systems for some of these buildings, although it is not clear if the system cost coupled with the increased fan electricity and air cleaning system costs would make retrofit underfloor ventilation competitive with other odor control technologies. If production costs are reduced as a result of less odorous pit air entering the animal breathing space (for example, medical or pharmaceutical costs may be reduced) by adding underfloor ventilation, these cost reductions would help pay for the system.

Windbreak Walls

Walls erected downwind from the fans that exhaust air from tunnel-ventilated poultry buildings are being used on more than 200 farms in Taiwan to limit dust and odor emissions from the buildings. These structures, known as windbreak walls, provide some blockage of the fan airflow in the horizontal direction. The walls work by reducing the forward momentum of airflow from the fans, which is beneficial during low-wind conditions, as odorous dust settles out of the airflow and remains on the farm. Recent research by scientists at NC State University indicates that windbreak walls also deflect fan airflow so that air flows higher above the ground or the surface of downwind lagoons. A study done in Iowa using a model predicted that tall wind barriers placed around a lagoon will reduce odor emissions from the lagoon. Although the operating cost of windbreak walls is relatively low, periodic cleaning of odorous dust from the walls is necessary for sustained odor control, unless rainfall is sufficient to clean the walls. Installation of windbreak walls is estimated to cost at least $1.50 per pig space (e.g. $1,500 for a building that houses 1,000 pigs).

Research to evaluate windbreak walls for dust and odor control is continuing in North Carolina and Taiwan. It is difficult to determine the effectiveness of windbreak walls due to several factors. As wind speed and direction shift, the airflow from building fans changes direction. As a result, it is difficult to measure odor downwind. Also, odors emitted from the lagoons complicate the situation. Several researchers believe that measurement of the impact of windbreak walls on airflow and the dust and odor levels in the airflow at the wall location should be incorporated into dispersion models to predict the downwind impacts of those emissions.

Windbreak walls would not be suited for animal buildings equipped with multiple fans at nonuniform locations around the building. However, special dustbreak devices have been designed for these situations and are being tested in Iowa. These devices employ a vertical plate to capture and settle dust particles. Experiments are being conducted with these vertical plates to see if they can be chemically treated to reduce odorous compounds.

Rows of trees and other vegetation known as shelterbelts, which have historically been used for snow control in colder climates, may have value as odor control devices and to create a visual barrier. A properly designed and placed shelterbelt could conceivably provide a very large filtration surface for both dust and odorous compound removal from building exhaust air. However, it may take several years to grow an effective vegetative windbreak. Studies indicate that trees in shelterbelts can absorb odorous compounds, and they create turbulence that enhances odor dispersion upward, particularly under stable nighttime conditions. This action accelerates the dilution of odorants. Shelterbelts should be inexpensive, especially if the cost is figured over the life of the shelterbelt. There is concern, however, that the roots of trees in a shelterbelt could disrupt the impervious layer of an anaerobic lagoon, causing the lagoon to leak. And research is needed to determine if vegetative windbreaks concentrate odor.

The success of windbreak walls in Taiwan, anecdotal accounts of windbreaks alleviating neighbor's concerns in the U.S., the relatively low operating cost of windbreak walls, and results of the North Carolina windbreak wall study are expected to stimulate further experimentation with airflow deflection devices such as windbreak walls downwind of animal buildings.

Washing Walls and Other Wet Scrubbers

Using water to scrub odorous dust and ammonia from the airflow from swine building ventilation fans can be an effective method of controlling odor. Indeed, many industrial air pollution control systems use sprays of water to scrub dust, ammonia and other gases from airflow. Some swine producers in the U.S. and Taiwan have tried spraying water into the fan airflow (e.g., spray nozzles are mounted on the fan housing). However, this approach may require a large amount of water unless the spray is collected and recirculated.

A wet scrubber design that recirculates most of the water through the system has been tested in North Carolina. This design involves a wetted pad evaporative cooling system installed in a stud wall about 4 feet upwind of ventilation fans and downwind of the pigs in a tunnel ventilated building. The producers and system designers have termed this a washing wall, since all of the ventilation airflow passes through the wet pad before being pulled through the fans, and some contaminants are washed from the air. The term wetted pad wall is more descriptive. Measurements show that the pad removes more than 60 percent of the dust at low (cool weather) ventilation rates and about 50 percent of the dust at medium ventilation rates. As expected, the dust was found to carry odorous compounds; therefore, dust removal should reduce odors downwind. The wetted pad wall also reduced ammonia levels in the ventilation airflow by 50 percent at low ventilation rates and 33 percent at a medium ventilation rate. It is possible that chemicals can be added to the pad water to enhance removal of ammonia and other odorous compounds. However, as a result of airflow rates and the 6-inch thickness of the pad, air spends little time inside the pad (less than 0.1 seconds at high ventilation rates) compared to industrial wet scrubbers used to clean airflow. Thus, there likely won't be time for many odor control products to work.

Wetted pad wall installation costs are approximately $5.70 per pig space for an 880-head finishing building. The main operating cost is the 1 hp water pump, which will have an annual cost of about $600. Most of the water is recycled, so water usage is very low. The water tank should be emptied occasionally as dust and dirt build up in the water. The wet pad is cleaned after every group of pigs, as is the rest of the building. The wetted pad wall is unusual and beneficial in that it provides some removal of odorous dust and ammonia without imposing a significant airflow restriction on the building fans, unlike industrial air filters and scrubbers. Maintaining adequate airflow is important if a healthy indoor environment is to be provided for the pigs in warm weather.

Biofilters and Biomass Filters

Biofilters may also be used to treat ventilation airflow moving through and out of swine buildings. Biofilters provide a medium for the growth of bacteria or other microbes that convert odorous compounds in the air to more benign products such as water, carbon dioxide and minerals. Air is forced through a biofilter at a slow enough rate that the odorous molecules are absorbed into the media on which the microbes are growing, and the microbes then do their work. Substances such as moist compost and wood chips serve as media in biofilters. Periodic moistening of the media is essential. Although they are widely regarded as an effective, low-cost method of cleaning industrial airflows, biofilters can still be considered an expensive odor control method on swine farms. They also require considerable management.

Experience with biofilters in Europe, the U.S. and elsewhere has shown that they can be very effective in removing odors from livestock building airflow, but challenging in terms of cost and management. For example, Minnesota researchers used a biofilter to clean air being pulled through a manure pit fan at a swine building. They minimized system costs by using existing materials, such as kidney bean straw grown by the farmer as media and inexpensive materials to build the filter. Seventy five to 90 percent of the odor was removed at a relatively low resistance to airflow. At NC State University, tests of three identical biofilters also showed they were effective in reducing odors from a swine building manure pit.

In another biofilter study in Minnesota at a 700-sow gestation/farrowing swine facility, odor was reduced by 95 percent and hydrogen sulfide by 90 percent. The amortized costs of biofilter construction and operating cost for three years was 22 cents per piglet produced. Included in construction and operating costs were increased fan power for higher pressure, air ducts, structural support for the biofilter media, the biofilter media and a sprinkler system to wet the media.

Biofilters may work well at low ventilation airflow rates. However, air must spend 5 to 10 seconds in the filter if the filter is to be effective. This means that a biofilter properly sized for high summer ventilation rates would be extremely expensive. Estimates of biofilter costs for cleaning all the airflow from swine buildings in warm weather have exceeded $200 per pig space. Since biofilters work best with very odorous air (rather than the more dilute air typical of high summer ventilation rates), it may be that biofilters can be used as a cool weather system, with a different system for treating odorous air in warm weather.

To remove the odorous dust from swine building airflow without the expense or resistance of biofilters, researchers at Iowa State University have been testing biomass filters. Airflow from a swine nursery building is directed through or over beds of chopped corn stalks and corn cobs, although other sources of biomass could be used. No attempt is made to wet the biomass to maintain a population of microorganisms, as is the case with biofilters. A biomass filter removes odorous dust from the air stream using inexpensive material. In one configuration, air is moved through three tiered, 6-inch thick beds of biomass. In another configuration, a series of vertical panels made from wooden 2 x 4 frames filled with biomass are arranged to force the airflow around the biomass, removing odorous dust. Both systems reduced odor and dust levels significantly (up to 90 percent reduction of odor and 80 percent reduction of dust). These reductions occurred with low resistance to airflow at cold weather ventilation rates.

Biomass filter research is encouraging. It remains to be seen, however, whether biomass filter systems can be designed for ease of biomass cleaning or replacement and to accommodate the higher ventilation rates needed in warm weather.

Manure Treatment Technologies to Mitigate Odor

Anaerobic Lagoons

Anaerobic lagoons are used by almost all North Carolina swine farmers to treat the wastes their pigs generate. Anaerobic lagoons act as biological systems in which bacteria decompose organic matter into gases, liquids and biosolids. Anaerobic bacteria in lagoons decompose organic matter and are predominantly used for treatment of the concentrated organic materials. Since the anaerobic process is not dependent on maintaining dissolved oxygen, lagoons can be much deeper and require less surface area than aerobic systems. Lagoon depth in North Carolina, however, is limited by groundwater levels. Anaerobic decomposition of livestock manure can result in the production and emission of odorous gases such as hydrogen sulfide and intermediate volatile organic compounds. When properly sized and managed, an anaerobic lagoon can be operated with a minimum of disagreeable odor. Volatile nitrogen gases are natural by-products of anaerobic decomposition and are released from open lagoon surfaces. The relative proportions of these compounds when released from a lagoon surface and their impact on the environment are not well documented or understood, although this is the subject of current research at NC State University and elsewhere.

Cattle manures have a higher percentage of relatively nondegradable fibrous material, which significantly increases the lagoon sludge buildup rate. For this reason, anaerobic lagoons are not generally used for treatment of cattle manure without prior solids settling, separation or removal.

Waste treatment lagoon designs are based on 40 years of research to optimize biological treatment processes for biochemical oxygen demand (BOD), odor and solids reduction. Anaerobic lagoons are designed to reduce BOD, the oxygen required by bacteria to stabilize decomposable organic matter. They also reduce the odor potential of the incoming untreated manure. Anaerobic lagoons provide 90 percent reduction of the BOD of incoming swine manure.

As lagoon capacity increases, odor potential, rate of sludge buildup and pathogenic organisms decrease while nitrogen losses increase. As open lagoon surface area increases, additional rainwater is collected and must be handled as wastewater. Because bacterial activity increases at higher temperatures, lagoons work best in areas without cold winters. The liquid capacity of an anaerobic lagoon should include the appropriate design treatment capacity, storage for accumulated sludge, and temporary storage for rainfall and wastewater inputs. In addition to this liquid capacity, surface storage for a 25-year, 24-hour rainfall and an additional foot of freeboard to prevent embankment overtopping are required.

A new lagoon should be filled to 50 percent of its permanent volume with liquid before manure loading begins. Start-up during warm weather and seeding with bottom sludge from a working lagoon will speed establishment of a stable bacterial population. Manure should be added to anaerobic lagoons as frequently as possible. Infrequent "shock" loadings can cause sharp increases in odor production and wide fluctuations in nutrient content. Liquid levels should not be allowed to fall below the design treatment level so that adequate volume is always available for optimum bacterial digestion.

An anaerobic lagoon that is operating properly will have a pH ranging from 7 – 8 (slightly basic). The pH in new lagoons without adequate dilution water or in overloaded lagoons can be reduced to 6.5 or less (acidic), thereby causing odor problems. This condition can be temporarily corrected by evenly distributing agricultural lime (preferably hydrated) on the liquid surface. Excessive additions of antibiotics or metals such as copper sulfate to animal feed may also have a negative effect on the bacterial populations in the lagoon and cause more potential for odor.

Many lagoons exhibit a reddish color in the liquid. The color is caused by naturally-occurring purple sulfur bacteria, phototrophic organisms that oxidize sulfide under anaerobic conditions. When these organisms are dominant, lagoon odor, ammonium nitrogen and soluble phosphorous are reduced. The red color is a good indicator of a lagoon working optimally.

Covers for Manure Collection and Treatment Structures

The storage structures that waste management systems use to collect and hold manure can be an odor source. These structures may be used for temporary storage of manure and wastewater until the contents can be spread on land or processed further. In North Carolina, the predominate collection and holding structure is the earthen lagoon, which is designed for biological treatment and sometimes for biogas collection. Covering such structures can reduce odor.

Storage structures are usually designed so that they may be completely emptied frequently. It must be possible, therefore, to remove the cover completely or partially so the structure can be emptied. Since storage structures have smaller relative surface areas, they lend themselves to being covered more readily than do larger treatment structures. Covering such structures can reduce odor and gas releases and minimize rainwater collection. Covers reduce wind-induced volatilization of gases and odor. Covers for storage structures should also allow for agitation of the material being stored and for pumping access.

Covers may be geomembranes such as high-density polyethylene or reinforced polypropylene materials. Such covers may float on the liquid surface or they can be supported above the liquid, which requires extensive structural installation. Geomembranes are costly, especially when supported above the liquid. Covers can be advantageous from a rainwater exclusion standpoint, but floating covers must have a reliable means of removing the rainwater from the cover or else the cover can sink below the wastewater level. Membranes exposed to the sun's ultraviolet rays tend to deteriorate and become brittle after a few years. Covers less than 20 mils thick have generally been unsuccessful because of sunlight blistering, which produces holes in the cover, or because of gas pockets under the cover, which can lead to wind-induced ruptures and tears. Covers today generally have a thickness in the range of 40-60 mils. Geomembrane covers are sometimes used on larger surface area treatment lagoons to capture biogas, which is then used as an alternative fuel. Because of the large surface area of treatment lagoons, such covers are costly. Covers supported above the liquid level are impractical because of the large surface area and the structural costs.

Biocovers, floating layers of slowly biodegradable materials, may also be used to cover manure storage structures. The natural crust that forms on the surface of a wastewater holding structure when animals are fed high-fiber diets is considered a biocover. Biocovers may also be made of chopped barley, wheat, flax, brome straw, corn stalks or peat moss. Such covers serve to either limit the volatilization of gases and odors from the surface of the stored contents or to filter these gases, reducing their odor levels. However, the cover materials tend to become waterlogged and sink to the bottom of the storage tank and must be replaced every 4-6 months. When these materials sink, the rate of sludge buildup tends to be increased, and it is much more difficult to pump manure solids and sludge from the structure.

Biocovers on large surface area treatment lagoons are impractical because of the huge amount of cover material needed; the tendency for the cover to break up as a result of wind and wave action; and the rapid rate of sludge buildup and difficulty of removing and handling the sludge.

Anaerobic Digesters

Anaerobic digesters are planned and managed to optimize the bacterial decomposition of organic matter. Organic material is stabilized, and gaseous by-products, primarily methane and carbon dioxide, are formed. Centralized anaerobic digesters, facilities that serve most of the livestock farms within a 6-mile radius, are used fairly extensively in Denmark for manure and odor management.

The expected methane yield from a digester system is needed for evaluation of the site-specific economics and for on-site energy use, management and marketing. One researcher recommends methane production of 24 cubic feet per 1,000 pounds live weight per day from swine manure. Biogas energy usually is used either for on-farm heating by means of a boiler or furnace or for cogeneration of electricity.

Early digesters in the form of enclosed tanks were designed to be operated in the mesophilic temperature range (68 to 113 degrees F) or in the thermophilic range (113 to 140 degrees F). Higher temperatures allow higher loading rates and, thus, smaller digesters. Higher temperature digestion also produces more efficient pathogen removal. However, the dynamics of thermophilic biological processes are more susceptible to disruptions and to failures than mesophilic biological processes. Flushing systems for waste removal from production systems widely used in warmer climates increase the size and cost of digesters. High initial costs have limited the number of digesters in the United States.

Psychrophilic (less than 68 degrees F) anaerobic digestion has been observed at temperatures approaching 40 degrees F. Because flushing systems and anaerobic lagoons already are in widespread use in warm regions, attention is being focused on earthen lagoon digesters with floating covers operating at ambient temperatures. This type of digester would potentially be less costly to construct and operate; however, the biogas production rate would be lower.

Effluent from mesophilic and thermophilic low-retention time digesters remains concentrated and can emit odors if not further treated or processed. Organic nitrogen is converted into ammonium-nitrogen during the anaerobic decomposition process, resulting in ammonium-rich effluent, which is subject to ammonia volatilization. Overall nutrients are not substantially reduced during the digestion process.

Considerable research has been devoted to recovery and reuse of biogas generated by anaerobic digesters as well as to the odor abatement potential of these systems; however, economics, equipment maintenance costs, erratic biogas production and increased managerial skill requirements have limited the adoption of this technology for manure utilization. It should be noted that the Danish systems referred to earlier are subsidized by the government to help cover capital and operating costs.

Solids Separation

The separation of the solid and liquid portions of the waste stream from swine buildings, known as solids separation, can reduce odor from lagoons by reducing the organic load being treated by the lagoon. Incorporating solids separation on an existing farm essentially makes the lagoon oversized for the waste load being treated, thus reducing odor. However, the odor potential of the separated solids should also be considered. While separated solids have potential as a valuable nutrient product (see composting below), if not properly handled, they can be a tremendous source of odors.

Composting

Composting is a naturally occurring controlled microbial process that converts solid organic material to carbon dioxide, water vapor, nutrients, minerals and reasonably stable organic matter. The composting process has long been used on farms to manage wastes and has also been used to manage municipal solid waste and municipal wastewater treatment plant biosolids.

Composting is a way to use the separated solids from a confined animal operation that provides a valuable, stable product. However, even though it is an aerobic process, the composting operation can generate significant odor.

Aerated Lagoons

Aerated lagoons use mechanical devices to add air to wastewater and promote the growth of aerobic bacteria. These organisms convert organic wastes to carbon dioxide and cell mass as they grow and multiply. Aerated lagoons mitigate odor by avoiding the anaerobic treatment environment that can produce odorous compounds. The biggest drawback to aerated lagoons is the cost of energy to run the units and the potential for release of ammonia if the aeration level is not correct. If too little oxygen is put into the system, the waste will not be stabilized and the anaerobic conditions that result will lead to additional odors. If too much oxygen is put into the system, ammonia and other gasses will be released. The biosolids produced by this and all other biological treatment systems must be collected, transported, processed, stored and utilized. There is the potential during all of these biosolid-related activities for significant odor production. Another drawback to aerated lagoons is that biosolids production is much higher than in anaerobic systems.

There are alternatives to complete aeration of the wastewater. If part of the organic waste is converted under aerobic conditions, lagoon odor emissions will be reduced. Partial aeration would, of course, lower the energy cost of aeration.

Aerobic Upflow Biofilters/Activated Sludge, Extended Aeration

Aeration is one of the proven methods of reducing odor from manure or wastewater. Aerobic treatment of manure does not allow the accumulation of volatile fatty acids and various other odorous compounds, so the odors are minimal during the treatment process. If aerobic treatment is sufficient to stabilize the waste, it can be stored for a long period without causing odor problems. There are many ways to supply oxygen to wastewater, such as compressed air diffusers, mechanical surface aeration and pumped liquid with venturi to incorporate air. Generally, transfer of oxygen to water requires considerable energy and is, therefore, expensive. If complete stabilization of the waste is desired, then the oxygenation capacity should be twice the total daily biochemical oxygen demand (BOD) of the waste with a hydraulic retention time of several days. Using an electrical energy cost of $0.07 per kilowatt hour, the power cost for running the aeration system continuously is about $11 per year per finishing pig space (each space will grow approximately 2.6 pigs per year). If partial odor control is desired, then the oxygen supplied could be less than twice the total daily BOD loading. For example, some odor reduction can be accomplished by supplying about a third of the BOD loading. This would cost about $1.80 per year per finishing pig space. However, aeration to supply only partial BOD removal could result in promoting ammonia volatilization, which may be an undesirable tradeoff. If nitrification/denitrification is also desired for reducing nitrogen (by releasing nitrogen gas to the air), then additional aeration above twice the BOD may be required.

Besides different methods to supply oxygen to the wastewater, there are various methods to promote retention of the bacteria responsible for waste treatment. Generally, these methods may be described as suspended media or fixed media. Examples of these two methods are an activated sludge treatment using recycled solids as a suspended media and a biofilter using fixed media to retain bacteria.

The activated sludge system has typically been used for municipal waste for complete stabilization, and thus would tend to have high energy costs for supplying twice the BOD loading. The biofilter system could be designed to satisfy all of the BOD or only part of the BOD, depending on the objectives. The operating costs and the odor of the effluent would depend on what degree of treatment is desired, and the energy costs would probably fall between the $1.80 and $11 per year per finishing pig space depending on degree of treatment (using the assumed energy cost of $0.07 per kilowatt hour). It should be noted that either system would likely require screening or removing the larger solids in the manure before the aeration treatment and would also produce biosolids from the treatment system. Both of these byproducts would tend to have more odor than the liquid discharged from the treatment system and would likely require more treatment, such as lime stabilization to eliminate odor.

Sequencing Batch Reactors (SBR)

A sequencing batch reactor is a fill-and-draw activated sludge treatment system. The unit processes involved in a sequencing batch reactor 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, whereas in a sequencing batch reactor, the processes are carried out sequentially in the same tank. As an aerated system, the same comments concerning ammonia and odor from those systems also apply to sequencing batch reactor systems.

Sequencing batch reactors have gained wide acceptance for removing biochemical oxygen demand (BOD) and nutrients from both municipal and industrial wastewater. This technology was initially used for the treatment of wastes from small communities and also for high-strength industrial wastewater, but recent large-scale applications have been reported. A sequencing batch reactor provides the opportunity for a great deal of control of the unit operations without the need for many separate tanks. The control of the unit operations means a system can be designed to the user's specifications; carbon removal, nitrogen removal, phosphorus removal can all be controlled, although not strictly independently. However, sequencing batch reactors produce biosolids or sludge, which must be stored, perhaps processed further, and can produce odor.

Ozonation

Ozone is a gas that reacts chemically with many compounds. Ozone high in the atmosphere acts to protect the earth from solar radiation. At ground level, however, the gas can be toxic. Ozone has been used as a disinfectant and deodorizing agent. Several laboratory and field evaluations of ozone treatments have been conducted or are ongoing. Belgian researchers obtained slightly improved daily growth and feed efficiency of finishing pigs as well as noticeable odor reduction by ozonating air in a finishing building. Researchers at Michigan State University reduced odorous compounds and disease-causing bacteria by treating swine manure slurry with high concentrations of ozone.

Due to the toxic nature of ozone, there is opposition to using ozone to treat indoor air spaces. Several professional groups including Occupational Safety and Health Administration and the American Lung Association have expressed concern that the levels of ozone required to effectively deodorize polluted indoor air often exceed recommended or permissible exposure limits for humans. There do not appear to be major objections to ozonating lagoon water from a human health standpoint, but health concerns with indoor ozone are likely to cause health and safety regulators to address lagoon ozonation as well. Nevertheless, the relatively high indoor odorant levels in some livestock buildings and the potential for ozone to be rapidly depleted, thus minimizing ozone emissions to outdoor air, continue to make ozonation of indoor air an attractive but controversial possibility. Some vendors have expressed keen interest in developing and marketing ozonation systems.

There are several ozone systems on the market, and some are being tested on livestock farms. One study involves a system in which ozone is generated inside specialized boxes, pulled into a swine building and distributed into the indoor air, and also pulled into a device floating on a lagoon and injected into the lagoon water in small bubbles. Odor reduction has been noticed in buildings and from lagoons when this system was in use. Since ozonated lagoon water can be recirculated into the building manure pits, this method can also reduce indoor odors by reducing odorous gases produced in the manure pits. However, long-term effects on lagoon treatment and sludge buildup have not been evaluated.

One particular ozone system for a swine finishing farm is projected to cost about $10,000 per building ($11 per pig space) for the ozone generating equipment and fans and tubes to distribute air in the building, and $50,000 to $60,000 for ozonating equipment for a large lagoon (roughly $6 to $7 per pig space for 10 buildings served by the lagoon). The electrical costs are likely to be the largest operating cost. The ozone generating cabinets draw roughly 700 watts, which, with four cabinets per building, could cost $1,000 or more per year ($1.14 per pig space per year), depending on electricity costs and operating time. The lagoon ozonator power levels are on the order of 10 kilowatts, which could handle up to 10 finishing buildings, which could then cost $6,000 or more per year for continuous operation, or $0.68 per pig space per year for 10 buildings. Since this technology has not been thoroughly tested, the costs may come down as ozonating requirements become better known. However, more testing is needed before ozonation of lagoons or air inside swine facilities can be recommended.

Control of Odor Emissions *from* Animal Operations

Product Additives

Product additives are generally described as compounds that can be added directly to freshly excreted or stored manure for purposes of odor abatement. There are hundreds of chemical and biological additives, masking agents and other commercial products that are being marketed to animal producers for odor management. In addition to odor management, many of these products are marketed as having other beneficial effects, including management of ammonia and hydrogen sulfide volatilization from stored manure; improved fertilizer value of the manure; fly control; improved animal health and feed conversion; and promotion of manure solids breakdown to enhance manure management and handling. Regarding odor abatement, these products can generally be grouped into several categories based on their mechanism of action.

Masking Agents. These are mixtures of compounds that have a strong characteristic odor of their own. They are designed to cover up, or mask, the targeted undesirable odor with a more desirable one;

Counteractants. These are mixtures of compounds that cancel or neutralize the targeted odor such that the intensity of the mixture is less than that of the constituents;

Digestive Deodorants. These contain bacteria or enzymes that eliminate undesirable odors through biochemical metabolic degradative processes;

Adsorbents. These products have a large surface area that may be used to adsorb targeted odors before they are released, or volatilized, to the environment;

Feed Additives. These are compounds incorporated into the animal's diet to improve animal performance and reduce targeted odors;

Chemical Deodorants. These are strong oxidizing agents or germicides that alter or eliminate microbial action responsible for odor production or chemically oxidize compounds that make up the undesirable odor mixture.

During the past 2 years, approximately two dozen of these product types have been evaluated by the NC State University Animal and Poultry Waste Management Center. An overview of the results is shown in the following table. In general, only a few of the products significantly improved odor parameters under the conditions tested.

Results of odor products evaluated by the NC State University Animal and Poultry Waste Management Center.*

Product Type	**Odor Reduction	***Cost (projected)
Microbial-1	2	L-M
Microbial-2	3	L-M
Microbial-3	3	L-M
Microbial-4	3	L-M
Microbial-5	2	L-M
Chemical-1	2	L-M
Microbial-6	2	ND****
Chemical-2	2	ND
Adsorbent-1	2	ND
Microbial-7	3	ND
Microbial-8	2	ND
Chemical-3	3	ND
Chemical-4	3	ND
Chemical-5	3	ND
Chemical-6	3	ND
Adsorbent-2	3	ND
Oxidizer-1	2	ND
Chemical-7	2	ND
Chemical-8	2	ND
Oxidizer-2	2	ND
Oxidizer-3	3	ND

*Results are based on research data collected to date; many of the products are in on-going stages of evaluation (laboratory and/or field) for impact on odor and economic analysis. Contact the NC State University Animal and Poultry Waste Management Center for specific product names and comprehensive final reports.

**Odor reduction effectiveness (1 = very effective; 2 = moderately effective; 3 = less effective)

***Cost (H = high; M = medium; L = low; see the economic section of this report for details on how high, medium and low costs were determined)

****Not determined. Economic analyses were done only for products evaluated in the field. If a product was evaluated in the laboratory only, an economic analysis was not done.

Control of Odor Emissions *from* Animal Operations

Researchers in Iowa are experimenting with products that are injected into the building air climate through high-pressure mister systems. The function of a periodic mist injection is to neutralize volatile odor compounds that accumulate in the building prior to being exhausted. No current conclusive results have been published on this type of system.

Other research has investigated the usefulness of manually spraying canola oil in a pig barn on a regular basis. Human health-damaging particles were reduced by 81 percent. A 50 percent reduction in odor intensity was measured with an odor panel, as compared with a control building, during this recent study. Hydrogen sulfide and ammonia levels in the air were reduced by 27 and 30 percent, respectively. This strategy could be automated to provide a very effective odor management technique and substantial benefit to indoor air quality. The estimated cost of $1.14 per pig produced was largely attributed (70 percent) to labor costs. A potential drawback, however, is the danger that oil-coated surfaces will be slippery, leading to injuries of people or animals.

Odor-Mitigating Factors and Concerns Relative to Other Waste Treatment Objectives

It must be realized that waste management is accomplished as a system of individual components acting on a larger system of animal production. As such, the objectives of each system must be considered when trying to optimize an individual component or aspect. Processes that reduce odor or individual odorous compounds might not be in the best interest of the larger waste treatment system, the animal production system, or the environment. Some specific concerns are described below.

Ammonia and Hydrogen Sulfide Emissions

Several processes, including air stripping and wastewater acidification, can affect ammonia in wastewater. Even though these techniques are known to improve odor, other goals of the system are negatively impacted. Air stripping can remove ammonia from the wastewater in confinement houses, but it merely moves the problem of ammonia downwind. Acidification prevents release of ammonia by converting it to the nonvolatile form, ammonium. This form remains in wastewater. However, hydrogen sulfide has an inverse relationship with pH from that of ammonia. When the pH is low and ammonia volatilization is low, hydrogen sulfide release is high. In addition, the lower pH resulting from this practice would cause corrosion problems for all equipment coming into contact with the water and may also prevent proper biological action in subsequent treatment components.

Total Nutrients

Extensive aerobic treatment will reduce odor from the liquid waste from a confined animal operation. In the process, however, much of the nutrient value will be lost. For example, much of the organic content of manure will be lost as carbon dioxide; nitrogen will be converted to nitrate and subsequently may be reduced to nitrogen gas.

Methane Emissions

Anaerobic digestion is a treatment technology that has been around for a long time. This technique can reduce the odors from the liquid waste from a confined animal operation. However, without consideration of the complete system, methane could be released to the atmosphere. This is undesirable because methane is a strong greenhouse gas.

Water Conservation

One way to reduce the emission rate of many odorous compounds from liquid waste treatment systems is to dilute the liquid with clean water. With more water, the various compounds can more easily dissolve rather than be released to the atmosphere. However, this is a poor use of valuable clean water and is contrary to the goal of water conservation. In addition, dilute wastewater can be more difficult or expensive to treat, depending on the degree of dilution and the degree of treatment desired. Therefore, this practice would make the associated treatment system extremely expensive.

Treatment system components

Treatment system components have been rated in the following table for cost and effectiveness in reducing odor and ammonia emissions. Care must be used in considering these ratings. These components do not all require the same amount of management. Mismanagement will lead to lower effectiveness and higher costs. Also, these components rely on the performance and management of other components - biosolids processing, for example - that must also be managed properly to achieve significant results.

nent assumes previous and subsequent processes are selected, installed and managed properly.

Industrial Odor Management

Various nonagricultural industries have been grappling with the problem of managing odor for some time, so it might seem appropriate to look to industrial odor management for methods of mitigating agricultural odor. However, odor management technologies that have been developed for nonagricultural use are generally too expensive for agricultural use. Among industrial odor management methods are condensation, incineration, wet scrubbing with chemical solutions, activated-carbon adsorption, biofiltration, odor modification and air dilution.

Condensation is an appropriate technique if the capture of a costly solvent from the odorous air is

Effectiveness and Cost of Waste Treatment System Components

System Component	Effectiveness*		
	Odor Emission Reduction	Ammonia Emission Reduction	Cost
Covered Reactors	1	1	H
Solids Separation	2	2	M
Composting	2	2	M
Anaerobic Digester	1	1	H
Anaerobic Lagoon	2	3	L
Aerated Lagoon	1	1	H
Sequencing Batch Reactor	1	1	H
Fixed-Media Aerated Biofilters	1	1	H
Activated Sludge	1	1	H

* Odor and ammonia emission reduction efficiency is rated numerically with 1 being the most effective and 3 the least effective. Cost is rated H for high, M for medium and L for low. The effectiveness shown for a given compo-

required. This clearly is not the case in an agricultural setting. Incineration can completely remove odors but at considerable initial investment and fuel operating costs. Multi-stage wet scrubbing would likely remove all odorous compounds from swine building exhaust air, but again at considerable cost. Activated carbon beds effectively deodorize highly odorous sources, but the cost of the carbon bed and carbon regeneration is economically prohibitive. Among industrial odor management methods, biofiltration and air dilution/ improved dispersion appear to be the only two methods appropriate for agricultural use, and both are being used for the control of animal building ventilation with some success.

Two popular industrial methods for the collection of dust emissions are cyclones and baghouse filters. The cyclone cleans particle-laden air with a spinning motion. Particles accelerate with the spinning air until the centrifugal force becomes great enough to push them to the cyclone wall. Next to the wall is a calm layer of air, which particles slide through into a hopper, where they can be collected. A baghouse filter, or bag filter, is simply an enclosure that supports several fabric filters much like the paper filters found in a home vacuum cleaner, only more durable.

Cyclones and baghouse filters are not thought to be practical for removing odorous particles from animal building ventilation air for two reasons. First is the wide range of ventilation rates needed for any animal building. Ventilation is responsible for removing heat and moisture from animal buildings, and is, therefore, dependent upon the outside temperature. Depending on the outside temperature, a typical building ventilation system must provide from approximately 10,000 cubic feet per minute to over 100,000 cubic feet per minute of airflow. Cyclones and baghouse filters are specially designed to operate in a narrow airflow range and would operate poorly over such a wide range. Cyclones and baghouses require at least 15-20 times the energy that the ventilation fans typically used on swine farms can provide.

The Bottom Line: Economics of Odor Management

Economics is the study of optimal resource allocation to achieve the maximum welfare for people. While economic variables are often converted to money for analysis, they actually represent basic resources such as land, labor, materials and energy. Higher costs represent higher resource use. Odor management is a classic economic decision. Undesirable odor can be a by-product of many human activities, including livestock production. Livestock production may be beneficial to the producers; to the income, employment and tax base of the community; and to consumers of livestock products. On the other hand, undesirable odor may degrade the quality of life of those exposed to the odor. Odor is particularly problematic to manage through policy because of the difficulty in measuring it; the range of human reactions to any given level of odorous compounds; and the variety of factors that affect the movement, intensity, duration and offensiveness of odors. In general, public policy has been designed to limit the effect of livestock odors on neighbors through nuisance law, through setback requirements, and through zoning while preserving farmers' rights to raise livestock using best management practices. Policy makers are challenged to design policies that balance the need for economic activity such as livestock production (which is critical to the welfare of many rural communities) with the need to provide reasonable protection for neighboring residences and competing land uses.

Farm Level Economics of Odor Management

Livestock farmers operate in a very competitive market. Profit margins are small on average and highly variable through time. Producers in competitive markets have virtually no control over the prices they receive for their products. They seek to maximize profits by minimizing costs through increased efficiency and reduced waste.

Livestock producers incur manure management costs for systems to remove manure from animal buildings as well as manure storage, treatment, transportation and land application systems. These costs may be partially offset by savings from reduced chemical fertilizer costs for crop land to which manure or treatment effluent is applied.

For example, swine finishing farms (raising pigs from 50 pounds to 250 pounds) in North Carolina may invest more than $40 per pig space (out of a total investment of $110 per pig space in this example) in slatted floors, flush systems, and ventilation equipment to remove manure, dust, gas and odors from swine barns. This investment in manure management facilities results in an annual amortization cost of $6 per pig space. If the building produces 2.6 groups of pigs each year, the amortization cost may be $2.30 per pig finished. (Note that this example excludes the farrowing and nursery phases of pig production.) North Carolina pig producers typically treat manure in anaerobic lagoons and irrigate liquid effluent from the lagoon onto crop or forage land. Net costs of this system may be $1.10 per pig finished (again excluding farrowing and nursery phases). Included in the $1.10 per pig are amortization costs for construction of the anaerobic lagoon for storage and treatment, amortization of irrigation equipment and spray field establishment, labor and electricity to operate the irrigation system, reduced crop income on land dedicated to spray fields, less the cost of chemical fertilizer saved on the spray field. An additional cost to anaerobic lagoon systems is the cost of removing sludge from the bottom of the lagoon after several years of accumulation. This cost can range from $.05 to $.90 per pig finished (excluding farrowing and nursery) depending on the method of sludge removal and the required frequency of sludge removal.

Increased costs will eliminate profits or create larger losses for some swine producers and reduce profits for the remaining producers. Unprofitable producers are forced out of business sooner or later. Profit is the difference between total revenue and total cost. Since swine producers have virtually no control over the price they receive for their pigs, any cost increase directly reduces their profit. Costs of production vary substantially across swine farms depending on their production, management and marketing efficiency. As a result, profit margins range substantially across hog farms from negative values (losses) for those farms that fail to cover total costs to positive values for farms with lower costs. Farms with repeated losses are forced out of business.

Costs of Odor Management Systems

The costs of installing alternative manure management systems (including odor management systems) on new farms can be compared to the cost of traditional manure management systems and categorized as high, medium and low. For direct comparison, the alternative system must provide all of the services provided by the traditional system (storage, treatment, transportation and land application or other nutrient removal). The cost of removing manure, dust, gas and odor from the barn is assumed to remain unchanged in the alternative systems. The following cost ranges may be useful in evaluating alternative manure and odor management systems. These cost ranges were used in the odor mitigation product additive evaluation table earlier in this report. The cost ranges were not used in either the waste treatment system component comparison table earlier in the report or in the farm management practice tables toward the end of the report. In both the system component evaluation and management practice tables, cost evaluations are based on the experience of researchers.

Cost of Manure Treatment for New Swine Finishing Facilities (Excluding Farrowing and Nursery)

Low: Less than $1.50 per pig finished

Medium: $1.50 to $3 per pig finished

High: Greater than $3 per pig finished

Included in these costs are the annual amortization of initial investments in equipment, buildings, land improvements and installation costs. Also included are annual operating expenses such as labor, management, electricity and fuel, repairs, supplies, custom service fees and royalties. Subtracted from the costs are any revenues or savings such as the value of chemical fertilizer saved or the income from manure sales. Net costs per pig space per year are divided by 2.6 pigs per pig space per year to obtain costs per pig finished.

Costs of retrofitting existing farms differ from costs of installing systems on new farms in that producers must still amortize investments in existing manure treatment systems as well as pay the full costs of installing and operating the retrofits. Therefore, cost categories for retrofits should be at least $1 per pig finished lower than the categories defined above. Rather than create a second set of categories, this report will repeatedly emphasize the economic differences between retrofits and installations on new farms.

Economics of Odor Management Policy

Changing policy toward odor management on livestock farms raises several issues that are critical to the welfare of rural communities, counties and regions in North Carolina. Whether through setbacks or odor standards or other policy instruments, the imposition of new restrictions on livestock production in North Carolina may have adverse impacts on the economic base of many rural communities, agricultural counties and regions. The competitive market for livestock means that any increase in costs will drive highly indebted producers and those whose operating costs are high out of business and reduce profits of the most efficient producers. Reduced profits and reduced production affect the farmers, the local businesses that supply them, the retail businesses and professionals that serve farmers, agribusinesses and their employees, the local and state tax base and local property values. On the other hand, policies allowing unrestricted odor emissions may result in social and political conflict, a diminished quality of life on the part of some neighbors, potential reductions in residential or recreational property values, and potentially altered development of surrounding land.

The odor management policy that maximizes the welfare of the people of North Carolina should have several features. First, it should not impose costs where little or no benefit is achieved. Previous attempts at environmental regulation have minimized costs by making regulations flexible to accommodate individual situations and to provide incentive for innovation. Second, it should be relatively simple and low-cost to implement and enforce. Third, it may incorporate cost share, tax credits, loan guarantees and other monetary incentives for retrofits to protect rural economic bases while reducing odor impacts. Fourth, it should rely heavily on scientific evidence and continuing research to establish and update parameters and approved practices.

Specific odor management policies have specific strengths and weaknesses. Policies requiring universal implementation of a specific odor management technology are considered inefficient because of their inflexibility. For example, the specified technology may impose a cost but have no benefit on farms that do not have odor problems.

Similarly, policies imposing an inflexible setback are inefficient in that the setback may be excessive in some situations and insufficient in others. As a result, productive farming is prevented in a place where it would not have created a problem, while neighbors are adversely affected in another situation. Further increasing an arbitrary setback unduly damages the economy of rural communities to the extent that livestock farming is prevented. The issue of setbacks is particularly difficult in North Carolina because of the relatively small size of farms (160 acres on average) and the irregular shape of many tracts of land in the state. Large setbacks have already precluded many rural landowners from producing livestock on a commercial scale. A positive aspect of setbacks is that they are easy to implement and enforce.

Flexibility has been added to setback determination in some situations by making the setback dependent on site-specific variables that affect odor emissions at the property line or at neighboring residences. The number of livestock, the type of livestock, the type of buildings, the type of manure management systems, the type of odor management systems, the local topography, the number of other livestock facilities nearby, and the general land use in the neighborhood are all factors that may affect the setback distance at which odor is perceived to be acceptable. Scientific verification of the relationship between such variables and perceived odor levels in North Carolina would be required to establish and update flexible setbacks. The acceptable level of odor targeted by flexible setbacks is still a policy decision. As stated above, an extremely low level of odor tolerance will have severe economic impacts in rural communities while an extremely high level of odor tolerance will sustain social and political conflict.

Odor standards can be a fairly flexible policy instrument in that they impose no specific practices on the farmer. Odor standards require some sort of reliable odor measurement technique and protocol. Enforcement of odor standards may be expensive depending on the cost of odor measurement. The flexibility of odor standards is also preserved through time: as new technology becomes available, a farmer can make changes to the farm without waiting for regulatory approval so long as the odor standard is adhered to. This policy would create strong incentives for innovation in odor management and odor prediction and measurement. The level of odor targeted by odor standards is still a policy decision. The targeted level might also be made contingent on local land use to minimize economic losses due to regulation.

Health Considerations Associated with Odorous Compounds

Inside Confined Animal Production Facilities

Aerial pollutants commonly found within animal facilities include dust, ammonia and other noxious gases, airborne bacteria, endotoxins (toxic substances produced by bacteria), and odorous compounds. In most cases these pollutants do not occur in sufficient concentration to pose acute health risks; they may not even be measurable. But acute and chronic health effects have been documented from exposure to animal house environments. Severe acute effects such as respiratory arrest and death have occurred in other states due to exposure to high levels of hydrogen sulfide, which can be released from manure pits under the floors of buildings or from external covered storage tanks when liquid manure is agitated. Hydrogen sulfide has not been considered a major health concern in North Carolina because most farms do not store untreated manure in pits or tanks. Building ventilation airflow rates are higher in North Carolina than in the Midwest so gases tend to be moved out of buildings relatively quickly. And the anaerobic lagoons used to treat manure in North Carolina do not generate high levels of hydrogen sulfide.

Dust in animal housing is primarily composed of feed components and dried fecal material but can also contain dander (hair and skin cells), molds, pollen grains, insect parts, mineral ash and, with floor-reared poultry, litter and feathers. Much of the dust and the endotoxins in livestock and poultry buildings is in the respirable size range; particles can be inhaled deep into human lungs and cause damage. Small particles can also deliver gases adsorbed onto them, such as ammonia and volatile organic compounds, deep into the lungs. Poultry and swine workers seem especially at risk, presumably due to higher dust levels and longer exposure times than in other animal housing.

Studies of swine facility workers have shown their most common respiratory symptoms to be increased coughing and phlegm production, which are dust-related and characterize bronchitis. Tightness of the chest, wheezing, organic dust toxic syndrome and reductions in pulmonary function have also been documented. Results for poultry workers are similar. In general, it appears that chronic effects such as reduced lung function and bronchitis are greatest among animal facility workers who have spent several years working in animal facilities.

Some of the constituents of the dust found in animal housing, such as animal dander, feed and feathers, can cause allergic responses. Since the air inside animal buildings typically contains several air pollutants, it can be difficult to ascribe respiratory effects to a single agent, and combinations of these pollutants may have an additive effect on human health.

Volatile organic compounds (VOCs) that make up odor can affect human health. Some of these compounds may cause sensory irritation, which is activated when VOCs come in contact with nerves in the eye, nose and throat. Symptoms in addition to irritation include cough, headache and drowsiness. Although the concentrations of individual compounds in an animal production environment are not likely to reach levels that cause acute toxicities, the combination of low levels of many compounds may additively produce sensory irritation of the eyes and free nerve endings in the nose and throat.

Since ventilation of animal buildings is necessary to remove heat from the animals' environment in warm weather, and the moisture they produce in warm and cool weather, ventilation also provides a means of removing air pollutants from the building and avoiding high indoor concentrations. Although indoor levels of dust, ammonia and endotoxins can often exceed recommended limits, some studies indicate indoor dust and ammonia levels do not always exceed recommended limits. Some researchers have argued for reduction of exposure limits since exposures at levels below current limits have been reported to cause health problems.

Outside Animal Production Facilities

Complaints of health problems are occurring with increasing frequency in communities surrounding areas where biosolids, animal manures and other byproducts are generated, stored, processed and utilized. Although it stands to reason that emission of odorous compounds that are objectionable to neighbors of livestock farms may also cause a health risk, there is a limited amount of evidence that serious risks to physical health occur. The same effects of dose and response occur in the outdoor, unconfined spaces, but outdoors, wind and atmospheric turbulence can effectively dilute the concentration of odorants. Measuring the concentrations of odors downwind of a livestock farm can be difficult for several reasons. Odor episodes can happen and change so quickly that an odor that causes a complaint may not be present in the same concentration or at all by the time a regulator or researcher arrives to measure the odor. Also, the human olfactory system is more sensitive than even the most precise instrumentation. However, research suggests that odor-causing substances can cause health effects such as eye, nose and throat irritation, headache and drowsiness, and possibly aggravate allergies, asthma, and bronchitis. Researchers at the University of Iowa studied neighbors living within a 2-mile radius of a 4,000-sow swine farm. Their results indicate that neighbors experienced significantly higher rates of symptoms, indicating toxic or irritating effects on the respiratory tract compared to other rural residents not living near livestock farms. They found little evidence that the swine farm neighbors experienced higher rates of anxiety or depression.

Due to the strong connections between the human olfactory system (where smells originate) and the brain, odors can affect mood and memory and may have other effects on brain functioning. For example, researchers at Duke University have shown that exposure to swine farm odors can adversely affect the moods of farm neighbors. Because unpleasant odors can produce impaired mood and stress, they may influence health through biological mechanisms that include changes in immune system function. Alterations in brain activity and memory have also been associated with odors.

Government agencies have recently become interested in whether odors from animal operations can cause health problems. At a recent workshop (April 16-17, 1998) at Duke University, participants indicated that while some levels of odorous compounds can cause negative health effects, the levels occurring downwind of livestock farms generally do not seem to be in the range that would be considered to cause severe physical health problems. This is presumably related to the fact that many odorous compounds on swine farms are present in concentrations that cause unpleasant odors but below concentrations that are considered to be acutely toxic to humans. On the other hand, increases in reports of asthma in areas with high concentrations of livestock production as well as recent studies that note numerous health problems reported from odors that may be of livestock origin cannot be ignored. (A report is now being prepared for the U.S. Environmental Protection Agency that provides a consensus of the workshop attendees regarding the health effects of odors.)

Societal Expectations and Social Consequences Relative to Odor and Its Management

Odor and other waste issues have a variety of social impacts and implications. These generally involve nuisance problems for neighbors, as well as broader community impacts. Concerns have been raised that animal waste represents a risk to public health, the environment and quality of life. Whether such risks are real or perceived is an important issue; however, what people believe to be real will have real consequences. The controversy over animal waste results from public reaction to a complex set of political, social, economic and psychological issues.

The committee preparing this report was charged with finding ways to obtain input from swine producer, environmental and community groups relative to what constitutes necessary and sufficient odor management considering economic, environmental and social consequences. This research, which employed focus groups, helped to accomplish that charge. Focus groups represent an effective and efficient way to collect information from a group of people. These groups use open-ended and qualitative discussions that provide detailed insights into people's attitudes and beliefs. Focus groups are not, however, designed to provide quantitative data from a representative sample of the population. Therefore, care must be taken when interpreting results from any focus group project.

For this project, we probed the attitudes and beliefs of residents of Sampson and Duplin counties through five focus groups held during June of 1998. One focus group was comprised of people considered opinion leaders from both Duplin and Sampson counties (referred to here as "leaders"). Another group was made up of swine producers from both Duplin and Sampson counties (called "producers" in this report). Another group included people who belong to organizations that have been active in raising concerns over swine issues. We called this group "activists." Two other groups were composed of Duplin and Sampson residents who did not fall into the other categories. We called them "citizens." The individual groups were made up of 12 opinion leaders, 13 swine producers, nine Duplin County citizens, seven Sampson County citizens, and 21 activists. Details on the selection and recruitment of focus group participants can be found in a more detailed report available from NC State University.

Each of the focus group sessions was professionally moderated. These discussions were taped and transcribed. The resulting verbatim transcripts were 25-35 single-spaced pages in length from each session. Two independent readers summarized the transcripts into a number of consistent themes. These summaries were reviewed by the entire research team. This report summarizes a number of important themes that emerged from the focus group discussions. The more detailed report also includes selected verbatim quotes from focus group participants.

Perceptions of Odor and Related Issues

The swine industry presents a number of inter-related social, economic, environmental and health related concerns. Members of the citizens and activists groups were concerned about the odor associated with the swine industry, as well as the industry's effect on the environment, residents' health, community cohesiveness and the local economy. Some citizens and activists were equally troubled by similar issues associated with poultry production. For the Duplin County citizens focus group, the swine industry is the most important problem facing their county. The Sampson County citizens focus group mentioned concerns with education and social issues as well as the swine issues. Members of the leaders and producers groups were concerned about the future of the swine industry, given the increasing regulations and public opposition to the industry.

Most citizens, activists as well as some leaders in the focus groups reported that they smell swine odor inside their homes and outside on their property. Very few people in the producers focus group reported that they smell swine odor at their homes.

Control of Odor Emissions *from* Animal Operations

Citizens and activists said they believe the odor comes from several sources: the waste lagoons, the spraying of waste on fields, dead animals and trucks. Citizens and activists group members who live near large-scale swine operations said odor is a relatively constant nuisance. Some noted that it is particularly bad on hot, humid days as well as when the wind is strong and blowing toward their homes.

It is not possible to precisely determine what will be necessary and sufficient odor management for all people at all times. On one hand, it is clear that the current situation is unacceptable to just about everyone. Members of all focus groups recognize the need for much more effective odor management. On the other hand, even the citizens and activists group members recognize that some level of odor from animal operations will be inevitable and is part of rural life. Members of the producers and leaders groups blame the media for much of the controversy over the swine industry. Citizens and activists did not mention the media, but attributed their concerns to direct personal experiences.

Members of the citizens group and all activists group members said that living with odor and flies from both swine and poultry has dramatically affected their lives. In addition to odor, they complained about the increase in flies since swine and poultry operations have opened. Those who live near animal operations said they can no longer enjoy going outside because of biting flies and odor. They said they no longer grill out, have parties or hang their clothes outside to dry. They said their children cannot go outside and play. Many talked about how they are embarrassed to have visitors because the smell permeates their homes and clothes. Some citizens and activists group members said they have changed their retirement and career plans because they believe they cannot sell their homes. They also said they feel the controversies have divided their communities.

Members of the citizens and activists groups said they are concerned about how animal waste and odor could harm residents' health. Leaders and producers group members did not think there are significant health effects. Some citizens and activists believe they have developed respiratory problems from the ammonia that emanates from swine operations. Others reported feeling nauseous from the odor. Citizens and activists group members were also concerned about diseases being transmitted from pigs to humans from drinking contaminated water or inhaling airborne particles.

Most members of the citizens and activists groups believe that the swine industry has a negative impact on the environment. They expressed serious concerns about animal waste contamination of drinking water and recreational waterways. Leaders group members believe that the swine industry could potentially harm the environment. Leaders and producers group members acknowledge there are "bad actors" in the industry who have not properly managed their operations, but they believe that most producers are good environmental stewards. Members of the producers group tend to think such environmental concerns are irrational. They emphasize that they need clean water and fertile land for animal production.

Leaders group members believe that the swine industry has brought economic growth to the area, but they also want a more diverse economic base. Producers group members contend that the swine industry has helped economically depressed counties prosper, especially in the wake of the decline in tobacco. In contrast, members of the citizens and activists groups believe that the swine industry has also had negative impacts on the local economy. They generally think that the swine industry has discouraged other industries (e.g., tourism) from locating in the area. They also believe that property values have declined. Overall, they believe that only the swine industry has benefitted. There also is disagreement among producers and citizens about who lived in the area first and should, therefore, have the right to use and enjoy their property.

Citizens, activists and leaders group members do respect and support local farmers. Many have connections to farming and see agriculture as an important part of their county's history and future. Citizens and activists group members expressed different views about corporate farms than about family farmers. Most of their concern and opposition was focused on intensive swine operations owned by "outsiders." They feel that too many swine and poultry houses were built in too short of a time span with no assessment of the impact to the existing residents. Concern was expressed for problems of smaller, family farms that have to cope with constantly changing laws and increasing competition.

Perceptions of Actions Needed

Citizens, activists, and leaders group members all agreed that swine farmers need to implement improved technology to better manage odor and waste. All groups strongly support more funding for research and technology development. In addition, they ask that farmers be more considerate of neighbors by: spraying only on days when the wind is not blowing; removing dead animals more promptly and more often; and putting out more fly traps and changing them more often. Several people also suggested that farmers create visual barriers to hide the operations from view. Producers group members said that if neighbors tell them when they are planning a barbecue or picnic, they would not spray on those days.

Improved communication and cooperation will be important. Members of the citizens and activists groups want farmers to come to their homes and see what they experience in terms of odor and flies. Producers group members said they want to educate residents on the ways in which they are trying to manage odor and better manage waste. Leaders group members suggested that farmers allow people to tour their operations and educate them about how they manage the animals and their waste. All participants want more opportunities to come together for open discussions to devise acceptable solutions to their common problems. Most participants expressed interest in attending additional mediated focus groups.

Most participants in the focus groups are frustrated with state government's response to the controversy about large-scale animal operations. All groups want state government to work harder to enforce the current regulations rather than implementing new ones. On one hand, citizens and activists group members think the swine industry controls legislators. On the other hand, leaders and producers group members think that legislators are too easily swayed by citizens' concerns. All participants in the focus groups want members of the General Assembly to visit their counties, homes and swine operations so that they can view the swine industry first-hand from the various perspectives.

Most people in the focus groups think the swine industry cannot sustain itself unless better methods to manage odor and manage waste are developed. Producers group members recognize that unless they manage odor controversies will continue to hurt their industry. Citizens and activists group members said they believe that if livestock producers do not become better neighbors and environmental stewards, they should no longer be able to continue large-scale animal production. In fact, members of the activists and Duplin County citizens groups said they want fundamental changes to occur in the industry. Essentially, they would like to go back to a family farming model of smaller operations where the owner/operator lives on site. Most citizens and activists group members are angry that many producers generally do not live near their operations and, therefore, do not have to contend with the odor and flies.

Future Directions

To effectively pursue the recommendations and initiatives outlined in this report, we need to know more about odor, about how, when and where it is generated on farms. We need to know more about air quality in animal confinement buildings, odor and dust emissions from animal confinement and other agricultural operations. The best way to develop this information is to collect air samples on North Carolina farms and analyze the samples for odor and air emission parameters such as dust. It would be desirable to determine this information for different size farms and from farms that use various ventilation, manure-handling systems and wastewater treatment methods.

The development of a database of odor parameters at various distances from odor sources will be a critical element in developing standards that describe acceptable odor and how often it will be acceptable. This information is also needed to determine objectively how serious odor complaints are. It will also help us determine which on-farm practices or treatments effectively reduce odor at property boundaries. For example, even though a treatment may reduce lagoon odor emission, does it also reduce odor from the farm to acceptable levels, considering that odors come from the animal production buildings also?

We should also continue to work to develop and validate air dispersion models capable of predicting odor intensity at distances from the source. Combined with odor emission data, the dispersion models could be a regulatory tool in determining reasonable setback distances for odor sources based on odor emission, meteorology and topography. Validation of the models with actual data is important.

The development of a durable and easily transportable electronic, or artificial, nose is needed. This will provide a more convenient method of measuring odors on-site. Such methods will be essential to effectively monitor odor emissions for performance standards enforcement. Continued efforts to identify tracer compounds that may correlate with odor perception are needed. There has been limited success in this area to date, but if a few compounds could be measured with equipment and methods already available that adequately identify odor intensity, this approach could potentially provide more accurate odor measurements than an electronic nose.

Studies of the odor-reduction effects of modified diet, additives to feed or stored manure, and treatment and management of manure should continue. Many show much promise.

Reports of health problems by persons living near swine operations have been documented in the scientific literature. Further research should be done to determine if these symptoms are associated with measurable physiological effects in a dose-response relationship.

Finally, more attention needs to be paid to understanding people's knowledge and attitudes about odor and other issues facing both the swine and poultry industries. It will be important to learn what factors influence these perceptions, including the relative role of the media compared to direct experience. It will also help to more systematically examine the support various groups have for different public policies and programs.

Appendix

Farm Management to Mitigate Odor

Livestock production and manure management systems often emit less odor and ammonia if farmers simply improve their managment practices such as keeping floors clean, removing manure accumulations frequently and regularly, keeping up with routine equipment maintenance, using feed additives to reduce dust and placing covers over flush tanks and open drain junction boxes. No system, regardless of how advanced the technology, will operate by itself without proper maintenance and management. Each farm owner and/or operator should first do an envrionmental assessment of their farm to check for possible sources of gas and odor emission and apply appropriate remedies before they spend an exhaustive and often unsuccessful search for an odor control "silver bullet." On-farm environmental/odor assessments by qualified professionals are available to livestock owners and growers. The following tables provide a menu of possible management remedies for odor, dust and ammonia emissions from livestock and poultry production farms. More detailed information on specific remedies can be found in fact sheets available from the Department of Biological and Agricultural Engineering at NC State University. Each Remedy is rated according to its effectiveness and cost. The ratings are based on professional judgement since many result from years of experience rather than controlled evaluations. Even though a particular remedy may have a low effectiveness rating, when combined with a grouping of remedies, it may still result in an overall improvement in conditions. Livestock farm owners and operators should never underestimate the value of using good judgement and common sense day-to-day management.

Swine Production Farm Management Practices to Mitigage Odor

	Odor Source	Cause	Possible Remedy	Effectiveness* Odor Emission Reduction	Effectiveness* Ammonia Emission Reduction	Cost**
1.	farmstead	swine production	vegetative or wooded buffers;	2	2	L
			recommended best management practices;	1	2	VL
			good judgment and common sense	1	1	VL
2.	animal body surface	dirty, manure covered animals	clean, dry floors	2	2	VL
3.	floor surface	wet, manure-covered floors	slotted floors;	2	2	M
			waterers located over slotted floors:	1	1	VL
			feeders at high end of solid floors;	2	2	VL
			scrape manure buildup from floors;	1	1	VL
			underfloor ventilation	2	2	M
4.	manure collection pit	urine; partial microbial decomposition	frequent manure removal by flushing, pit recharge, or scraping;	1	2	L
			underfloor ventilation	2	2	M

*The odor and ammonia emission reduction effectiveness of each remedy is rated numerically, with 1 being the most effective and 3 the least effective.

**Cost is rated H for high, M for medium, L for low and VL for very low.
All ratings are based on the professional judgement of scientists at NC State University. Even though a possible remedy by itself may be rated low, when combined with a grouping of remedies, it may result in an overall improvement. More detailed information on several of the possible remedies may be available in fact sheets from the Department of Biological and Agricultural Engineering at NC State University.

Swine Production Farm Management Practices (continued)

Odor Source	Cause	Possible Remedy	Effectiveness* Odor Emission Reduction	Effectiveness* Ammonia Emission Reduction	Cost**
5. pit exhaust fan	gases; dust	fan maintenance;	2	3	VL
		air scrubbing;	2	2	H
		biomass filters;	2	2	M
		biofiltration;	2	2	H
		wind break walls	2	3	L
6. side/end wall exhaust fan	gases; dust	fan maintenance and efficient air movement;	2	3	L
		air scrubbing;	2	2	H
		biomass filters;	2	2	M
		biofiltration;	2	2	H
		wind break walls	2	3	L
7. feeder	dust	feed additives;	2	3	L
		feeder covers;	1	3	L
		feed delivery downspout extenders	1	3	VL
8. indoor surfaces	dust	washdown between groups of animals;	1	3	L
		proven oil atomization techniques	2	3	L
9. outside feed tanks	spilled moldy feed	keep mechanical equipment in good repair	3	3	VL
		remove spilled feed promptly	2	3	VL
10. flush tank	agitation of recycled lagoon liquid while tank is filling	flush tank cover;	2	2	L
		extend fill line to near bottom of tank with anti-siphon vent	2	2	VL
11. flush alley	agitation of recycled lagoon liquid while flowing down alley	underfloor flush with underfloor ventilation	3	3	M
12. pit recharge	agitation of recycled lagoon liquid while pit is filling	extend recharge line to near bottom of pit with anti-siphon vent	2	2	VL

*The odor and ammonia emission reduction effectiveness of each remedy is rated numerically, with 1 being the most effective and 3 the least effective.

**Cost is rated H for high, M for medium, L for low and VL for very low.
All ratings are based on the professional judgement of scientists at NC State University. Even though a possible remedy by itself may be rated low, when combined with a grouping of remedies, it may result in an overall improvement. More detailed information on several of the possible remedies may be available in fact sheets from the Department of Biological and Agricultural Engineering at NC State University.

Appendix

Swine Production Farm Management Practices (continued)

Odor Source	Cause	Possible Remedy	Effectiveness* Odor Emission Reduction	Ammonia Emission Reduction	Cost**
13. lift stations	agitation during sump tank filling and drawdown	sump tank covers	2	3	VL
14. outside drain collection	agitation of wastes while pit or junction box is draining	box covers	2	3	VL
15. end of drainpipe at lagoon	agitation of wastes while pit is draining	extend discharge point of pipe underneath lagoon liquid level	1	2	VL
16. lagoon surface	incomplete microbial decomposition; biological mixing; agitation	proper lagoon liquid capacity;	1	2	M
		correct lagoon startup procedures;	1	3	M
		minimum surface area-to-volume ratio;	2	2	L
		minimum agitation when pumping	1	2	L
		mechanical aeration;	2	2	H
		lagoon cover;	1	1	H
		proven biological additives	3	3	M
17. irrigation sprinkler nozzle	high pressure agitation; wind drift	irrigate on dry days with little or no wind;	2	3	VL
		minimum recommended operating pressure;	2	3	L
		pump intake near lagoon liquid surface;	2	3	VL
		pump from second-stage lagoon	2	2	M
18. storage basin surface	partial microbial decomposition; mixing while filling; agitation when emptying	bottom or midlevel loading;	2	2	M
		surface mat of solids;	1	2	L
		proven biological additives or oxidants	1	1	M
19. settling	partial microbial decomposition; mixing while filing agitation when emptying	extend drainpipe outlet underneath underneath lagoon liquid level;	1	2	L
		basin cover;	1	1	H
		remove settled solids regularly	1	2	M

*The odor and ammonia emission reduction effectiveness of each remedy is rated numerically, with 1 being the most effective and 3 the least effective.

**Cost is rated H for high, M for medium, L for low and VL for very low.
All ratings are based on the professional judgement of scientists at NC State University. Even though a possible remedy by itself may be rated low, when combined with a grouping of remedies, it may result in an overall improvement. More detailed information on several of the possible remedies may be available in fact sheets from the Department of Biological and Agricultural Engineering at NC State University.

Swine Production Farm Management Practices (continued)

Odor Source	Cause	Possible Remedy	Effectiveness* Odor Emission Reduction	Effectiveness* Ammonia Emission Reduction	Cost**
20. manure, slurry or sludge spreader outlet	agitation when spreading	soil injection of slurry/sludge;	2	2	H
		proven biological additives or oxidants	3	3	M
21. uncovered manure, slurry or sludge on field surface	microbial gases while drying	soil injection of slurry/sludge;	2	2	H
		soil incorporation within 48 hours;	2	2	M
		spread in thin uniform layers for rapid drying;	2	2	M
		proven biological additives or oxidants	3	3	M
22. dead animal	carcass decomposition	proper disposition of carcass	1	3	L
23. dead animal disposal pit	carcass decomposition	complete covering of carcass in burial pit;	1	3	M
24. incinerator	incomplete combustion	secondary stack burner	2	3	H
25. standing water around facilities	improper drainage; microbial decomposition of organic matter	grade and landscape such that water drains away from facilities	2	3	L
26. mud tracked to public roads from farm access roads	poorly maintained access roads	access road maintenance	2	3	L

*The odor and ammonia emission reduction effectiveness of each remedy is rated numerically, with 1 being the most effective and 3 the least effective.

**Cost is rated H for high, M for medium, L for low and VL for very low.
All ratings are based on the professional judgement of scientists at NC State University. Even though a possible remedy by itself may be rated low, when combined with a grouping of remedies, it may result in an overall improvement. More detailed information on several of the possible remedies may be available in fact sheets from the Department of Biological and Agricultural Engineering at NC State University.

Appendix

Dairy Production Farm Management Practices to Mitigate Odor

Odor Source	Cause	Possible Remedy	Effectiveness* Odor Emission Reduction	Effectiveness* Ammonia Emission Reduction	Cost**
1. farm	dairy production	vegetative or wooded buffers;	2	2	L
		recommended best management practices;	1	2	VL
		good judgment and common sense	1	1	VL
2. paved lot or barn, alley surfaces	wet, manure-covered surfaces	scrape or flush surfaces daily;	2	2	M
		promote drying with proper ventilation;	1	2	L
		routine checks and maintenance on waterers, hydrants, pipes, stock tanks	2	2	L
3. commodity storage sheds or tanks	partial microbial decomposition and moldy feedstuffs	remove accumulations of spoilage	2	3	L
4. silo	bunker spoilage; microbial fermentation of freshly cut silage	remove accumulations of spoilage;	2	1	L
		divert liquid drainage to a grassy soil surface in thin uniform layers for rapid drying	3	3	L
5. feed bunk	moldy feedstuff	keep mechanical equipment in good repair;	3	3	L
		remove uneaten feedstuff accumulations	3	3	L
6. bedded areas	urine and partial microbial decomposition	promote drying with proper ventilation;	2	2	L
		replace wet or manure-covered bedding	2	2	M
7. manure dry stack	partial microbial decomposition	provide liquid drainage for stored manure	2	2	M
8. manure storage basin surface	partial microbial decomposition; mixing while filling; agitation when emptying	bottom or midlevel loading;	2	2	M
		surface mat of solids;	2	2	L
		minimize lot runoff and liquid additions;	2	2	M
		agitate only prior to manure removal;	1	2	L
		proven biological additives or oxidants	3	3	M
9. settling basin surface	partial microbial decomposition; mixing while filling; agitation when emptying	liquid drainage from settled solids;	3	3	M
		remove settled solids regularly	2	3	M
10. manure, slurry or sludge spreader outlet	agitation when spreading	soil injection of slurry/sludge;	2	2	H
		proven biological additives or oxidants	3	3	M
11. uncovered manure, slurry or sludge on field surface	microbial gases while drying	soil injection of slurry/sludge;	2	2	H
		soil incorporation within 48 hours;	2	2	M
		spread in thin uniform layers for rapid drying;	2	2	M
		proven biological additives or oxidants	3	3	M

*The odor and ammonia emission reduction effectiveness of each remedy is rated numerically, with 1 being the most effective and 3 the least effective.

**Cost is rated H for high, M for medium, L for low and VL for very low.
All ratings are based on the professional judgement of scientists at NC State University. Even though a possible remedy by itself may be rated low, when combined with a grouping of remedies, it may result in an overall improvement. More detailed information on several of the possible remedies may be available in fact sheets from the Department of Biological and Agricultural Engineering at NC State University.

Dairy Production Farm Management Practices to Mitigate Odor (continued)

Odor Source	Cause	Possible Remedy	Effectiveness* Odor Emission Reduction	Effectiveness* Ammonia Emission Reduction	Cost**
12. flush tank	agitation of recycled lagoon liquid while tank is filling	flush tank cover;	2	2	L
		extend fill line to near bottom of tank with anti-siphon vent	2	2	VL
13. outside drain collection or junction box	agitation of wastes while pit is draining	box covers	2	3	VL
14. lift stations	agitation during sump tank filling and drawdown	sump tank covers	2	3	VL
15. end of drainpipe at lagoon	agitation during wastewater conveyance	extend discharge point of pipe underneath lagoon liquid level	1	2	VL
16. lagoon surface	incomplete microbial decomposition; biological mixing; agitation	proper lagoon liquid capacity;	1	2	M
		correct lagoon startup procedures;	1	3	M
		minimum surface area-to-volume ratio;	2	2	L
		minimum agitation when pumping;	1	2	L
		mechanical aeration;	2	2	H
		lagoon cover;	1	1	H
		proven biological additives	3	3	M
17. irrigation sprinkler nozzle	high pressure agitation; wind drift	irrigate on dry days with little or no wind;	2	3	VL
		minimum recommended operating pressure;	2	3	L
		pump intake near lagoon liquid surface;	2	3	VL
		pump from second-stage lagoon;	2	2	M
		flush solids from lines at end of slurry/sludge pumping	2	3	L
18. dead animal	carcass decomposition	proper disposition of carcass;	1	3	L
19. contaminated milk	partial microbial decomposition	transport to approved processing plant;	2	3	L
		transport to approved wastewater treatment plant;	2	3	L
		add to farm lagoon and submerge in liquid;	2	3	M
		land apply and soil incorporate	2	3	M
20. standing water around facilities	improper drainage; microbial decomposition of organic matter	grade and landscape such that water drains away from facilities	2	3	L
21. mud tracked onto public road from farm access	poorly maintained access roads	farm access road maintenance	2	3	L

*The odor and ammonia emission reduction effectiveness of each remedy is rated numerically, with 1 being the most effective and 3 the least effective.

**Cost is rated H for high, M for medium, L for low and VL for very low.
All ratings are based on the professional judgement of scientists at NC State University. Even though a possible remedy by itself may be rated low, when combined with a grouping of remedies, it may result in an overall improvement. More detailed information on several of the possible remedies may be available in fact sheets from the Department of Biological and Agricultural Engineering at NC State University.

Appendix

Poultry Layer Production Farm Management Practices to Mitigage Odor

Odor Source	Cause	Possible Remedy	Effectiveness* Odor Emission Reduction	Effectiveness* Ammonia Emission Reduction	Cost**
1. farmstead	poultry production	vegetative or wooded buffers;	2	2	L
		recommended best management practices;	1	2	VL
		good judgment and common sense	1	1	VL
2. floor surface (walk aisles)	wet, dirty surfaces	scrape manure, dust, feathers into manure alley;	2	3	L
		splash boards along upper end of flush alley;	1	2	VL
		proper ventilation	2	2	M
3. cage battery manure dropping boards	manure-covered surfaces	scrape manure into manure alley or pit	1	2	L
4. manure collection pit or alley	partial microbial decomposition	scrape or flush alley daily;	1	2	L
		recirculate air over deep-pit stored manure	2	2	M
5. pit exhaust fan (deep pit)	gases, dust	fan maintenance;	2	3	VL
		air scrubbing;	2	2	H
		biomass filters;	2	2	M
		biofiltration;	2	2	H
		windbreak walls	2	3	L
6. side/end wall exhaust fan	gases, dust	fan maintenance and efficient air movement:	2	3	L
		air scrubbing;	2	2	H
		biomass filters;	2	2	M
		biofiltration;	2	2	H
		windbreak walls	2	3	L
7. indoor surfaces	dust	vacuum or washdown between flocks of birds;	1	3	L
		proven oil atomization techniques	2	3	L
8. watering system maintenance	excessively wet stored manure	frequent checks and maintenance of waterers and water pipes	2	2	VL
9. outside feed tanks	spilled moldy feed	keep mechanical equipment in good repair	3	3	VL
		remove spilled feed promptly	2	3	VL
10. manure conveyors	partial microbial decomposition	keep mechanical equipment in good repair;	2	2	L
		remove manure accumulations promptly	1	2	L
11. storage basin surface	partial microbial decomposition;	bottom or midlevel loading;	2	2	M
	mixing while filling;	surface mat of solids;	1	2	L
	agitation when emptying	proven biological additives or oxidants	3	3	M

*The odor and ammonia emission reduction effectiveness of each remedy is rated numerically, with 1 being the most effective and 3 the least effective.

**Cost is rated H for high, M for medium, L for low and VL for very low.
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Poultry Layer Production Farm Management Practices to Mitigage Odor (continued)

Odor Source	Cause	Possible Remedy	Effectiveness* Odor Emission Reduction	Effectiveness* Ammonia Emission Reduction	Cost**
12. settling basin surface	partial microbial decomposition;	liquid drainage from settled solids;	3	3	L
	agitation while filling/emptying	remove settled solids regularly	2	3	L
13. manure, slurry or sludge spreader outlet	agitation when spreading	soil injection of slurry/sludge;	2	2	H
		proven biological additives or oxidants	3	3	M
14. uncovered manure, slurry or sludge on field surface	microbial gases while drying	soil injection of slurry/sludge;	2	2	H
		soil incorporation within 48 hours;	2	2	M
		spread in thin uniform layers for rapid drying;	2	2	M
		proven biological additives or oxidants	3	3	M
15. flush tank	agitation of recycled lagoon liquid while tank is filling	flush tank cover;	2	2	L
		extend fill line to near bottom of tank with anti-siphon vent	2	2	VL
16. outside drain collection or junction box	agitation of wastes while pit is draining	box covers	2	3	VL
17. lift stations	agitation during sump tank filling and drawdown	sump tank covers	2	3	VL
18. end of drainpipe at lagoon	agitation of wastes while pit is draining	extend discharge point of pipe underneath lagoon liquid level	1	2	VL
19. lagoon surface	incomplete microbial decomposition; biological mixing; agitation	proper lagoon liquid capacity;	1	2	M
		correct lagoon startup procedures;	1	3	M
		minimum surface area-to-volume ratio;	2	2	L
		minimum agitation when pumping;	1	2	L
		mechanical aeration;	2	2	H
		lagoon cover;	1	1	H
		proven biological additives	3	3	M
20. irrigation sprinkler nozzle	high pressure agitation; wind drift	irrigate on dry days with little or no wind;	2	3	VL
		minimum recommended operating pressure;	2	3	L
		pump intake near lagoon liquid surface;	2	3	VL
		pump from second-stage lagoon	2	2	M
22. dead bird	carcass decomposition	proper disposition of carcass	1	3	L
23. dead bird disposal pit	carcass decomposition	complete covering of disposal pit openings;	1	3	M

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Appendix

Poultry Layer Production Farm Management Practices to Mitigage Odor (continued)

Odor Source	Cause	Possible Remedy	Effectiveness* Odor Emission Reduction	Effectiveness* Ammonia Emission Reduction	Cost**
24. incinerator	incomplete combustion	secondary stack burner	2	3	H
25. dead bird composter	partial microbial decomposition	proper compost recipe;	2	2	L
		proper compost pile formation	1	2	M
26. cull or broken egg disposal	partial microbial decomposition	collect and remove promptly	1	3	L
		proper disposition	2	3	M
27. standing water around facilities	improper drainage; microbial decomposition of organic matter	grade and landscape such that water drains away from facilities	2	3	L
28. mud tracked onto public roads from farm access	poorly maintained access roads	farm access road maintenance	2	3	L

Poultry Broiler/Turkey Production Farm Management Practices to Mitigate Odor

Odor Source	Cause	Possible Remedy	Effectiveness* Odor Emission Reduction	Effectiveness* Ammonia Emission Reduction	Cost**
1. farmstead	poultry production	vegetative or wooded buffers;	2	2	L
		recommended best management practices;	1	2	VL
		good judgment and common sense	1	1	VL
2. floor surface	excessively wet litter	proper ventilation;	2	2	M
		properly adjusted and operated foggers/misters	2	2	L
3. floor surface	dust	proper ventilation	2	3	M
4. side/end wall exhaust fan	gases; dust	fan maintenance and efficient air movement;	2	3	L
		air scrubbing;	2	2	H
		biomass filters;	2	2	M
		biofiltration;	2	2	H
		windbreak walls	2	3	L

*The odor and ammonia emission reduction effectiveness of each remedy is rated numerically, with 1 being the most effective and 3 the least effective.

**Cost is rated H for high, M for medium, L for low and VL for very low.
All ratings are based on the professional judgement of scientists at NC State University. Even though a possible remedy by itself may be rated low, when combined with a grouping of remedies, it may result in an overall improvement. More detailed information on several of the possible remedies may be available in fact sheets from the Department of Biological and Agricultural Engineering at NC State University.

Poultry Broiler/Turkey Production Farm Management Practices to Mitigage Odor (continued)

Odor Source	Cause	Possible Remedy	Effectiveness* Odor Emission Reduction	Ammonia Emission Reduction	Cost**
5. indoor surfaces	dust	vacuum or washdown between flocks of birds;	2	2	L
		proven oil atomization techniques	2	3	L
6. watering system maintenance	excessively wet litter	frequent checks and maintenance on waterers and water pipes	2	2	VL
7. outside feed tanks	spilled moldy feed	keep mechanical equipment in good repair;	3	3	VL
		remove spilled feed promptly	2	3	VL
8. stockpiled litter	partial microbial decomposition;	store litter under cover or roof;	2	3	M
		store litter on compacted or paved surface;	3	3	M
		direct leachate in thin layers onto grassy filtration areas	3	3	L
9. litter spreader outlet	dust; wind draft	spread on days with little wind	2	3	M
10. uncovered wet litter on field surface	microbial gases while drying	soil incorporation within 48 hours;	2	3	M
		spread in thin uniform layers for rapid drying	3	3	M
11. dead bird	carcass decomposition	proper disposition of carcass	1	3	L
12. dead bird disposal pit	carcass decomposition	complete covering of disposal pit openings;	1	3	M
13. incinerator	incomplete combustion	secondary stack burner	2	3	H
14. dead bird composter	partial microbial decomposition	proper compost recipe;	2	2	L
		proper compost pile formation	1	2	M
15. standing water around facilities	improper drainage; microbial decomposition of organic matter	grade and landscape such that water drain s away from facilities	2	3	L
16. mud tracked onto public roads from farm access	poorly maintained access roads	farm access road maintenance	2	3	L

*The odor and ammonia emission reduction effectiveness of each remedy is rated numerically, with 1 being the most effective and 3 the least effective.

**Cost is rated H for high, M for medium, L for low and VL for very low.
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