Agricultural Air Quality Conservation Measures

Reference Guide for Poultry and Livestock Production Systems

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Introduction

The United States Environmental Protection Agency (EPA) and the United States Department of Agriculture (USDA) have collaborated to develop this reference guide to provide a compilation of conservation measures for air pollutant emission reductions and/or reduction of air quality impacts from livestock and poultry operations. Agricultural land management and cropping operations have been covered in a separate reference guide. This reference guide can be used to address agriculturally-related air resource concerns in areas where agricultural emissions from livestock operations are determined to be significant contributors to air quality impairment. The methods presented in this guide are consistent with USDA objectives that promote the use of cost-effective practices and innovative technologies to address air resource concerns from agricultural operations and to meet federal, state and local regulatory requirements. The effectiveness of each of the measures is dependent on site-specific conditions at each operation. Some of the measures have been studied specifically in agricultural settings; Appendix 1 contains a table listing the ranges of emission reductions reported in the literature for these measures. Many of the measures provided in this guide also have additional resource benefits such as soil, water or energy conservation. Some co-benefits are identified, but this document is primarily focused on air quality.

Over the years, EPA has received requests to identify measures that may be considered to manage air emissions from livestock operations and potentially satisfy State Implementation Plan requirements. These requests have come from a variety of stakeholders, including USDA's Agricultural Air Quality Task Force, agricultural producers, industry representatives and state and local agencies.

This reference guide is designed as a technical tool to provide a compilation of approved practices from the USDA Natural Resources Conservation Service (USDA-NRCS) to address air emissions from livestock and poultry operations in areas where those operations have been demonstrated to contribute to air quality issues. To learn more about USDA-NRCS practice standards please contact your local USDA-NRCS state office. Contact information for USDA-NRCS state offices can be found under the "Contact Us" link at www.nrcs.usda.gov. USDA-NRCS may be able to offer technical and financial assistance to agricultural producers for implementing these and other conservation practices and enhancements.

Furthermore, the USDA-NRCS was involved in the development of additional conservation measures for air quality purposes in California and Arizona and, where appropriate, references to these USDA-NRCS approved measures are included in this guide. Some of these conservation activities were patterned after USDA-NRCS conservation practice standards, but despite similarities in some of the names, application of these conservation activities may differ slightly from application of the USDA-NRCS practice standards. Additional conservation practices that have been promoted by state/regional air quality programs and universities with agricultural extension services are included in this guide. The description of each conservation measure identifies related USDA-NRCS approved practice standards and/or the state or university programs that support the measure. Appendices 2 and 3 provide links to these programs that can be consulted for further information on the included conservation measures.

This Reference Guide Is Intended to:

- Provide a broad, though not comprehensive, set of USDA-NRCS approved and other demonstrated practices that may be applied to address air resource concerns.
- Provide regional, state and local regulatory agencies with technical tools and information on how to manage agricultural air emissions with USDA-NRCS approved and other demonstrated measures, and USDA and EPA expertise.
- Allow stakeholders the flexibility in choosing which measures are best suited for their specific situations/conditions and desired purposes.

This Reference Guide Is NOT Intended to:

- Provide any regulatory measures from the EPA.
    - This document is solely for informational purposes. It may be useful for states and local air agencies needing additional information on available options for reducing emissions in areas that have a nonattainment designation.
- Provide a comprehensive listing of all potential emissions reduction measures for mitigating agriculturally-related air quality impacts.
- Provide conservation measures that will be suitable for every specific case.
    - Geographic location, environmental conditions and intended purposes will differ for each particular agricultural situation. Thus, USDA and the EPA strongly encourage state and local agencies to work with individual producers and USDA-NRCS conservationists to develop plans that include feasible and effective measures for each site.
- Provide details about the numerous co-benefits these measures may offer with respect to water quality, soil health, energy savings and others.
    - Many of the practices listed in this guide may already be implemented to achieve other resource benefits (e.g., soil conservation, water conservation). This document was designed to solely focus on the air quality benefits achieved from implementation of the conservation measures. It should be noted that in some cases, measures taken to achieve air quality benefits may cause other environmental impacts and each situation needs to be carefully analyzed to achieve mutually beneficial outcomes.

Implementing Conservation Measures

Techniques to mitigate air emissions from animal production systems can focus on different approaches to mitigate the impact of these emissions – either the *generation* of the gas/pollutant, the *emission* or release of the generated gas/pollutant or the *transport* (movement) of those gases/pollutants. Strategies that reduce the generation of a pollutant are usually the most cost-effective and may provide other operational, financial or environmental benefits to the operation. Strategies to reduce emissions and improve air quality often impose additional costs to an operation without providing additional benefits to the farm (beyond the reduction in emissions) and there are few strategies that effectively prevent the transport of pollutants once they have been released to the atmosphere. This document discusses various technologies and/or management activities that can be used to mitigate air emissions from animal production systems. In general, when implementing these conservation measures:

- Regional, state and local regulatory agencies should coordinate (as appropriate) with the producers, landowners, operators, state and local agencies, USDA-NRCS and the EPA to determine which measures may be best suited for a particular situation to attain the desired goals.
- Consider the geographic location and environmental conditions (e.g., soil type, precipitation, humidity, temperature, water availability, wind conditions, terrain), management practices (e.g., feed, manure) and operating conditions (e.g., animal species, housing/confinement type) in which the practices will be implemented, as they will also play a role in deciding which conservation measures are most suitable.
- Assess implementation costs and benefits to determine the most cost-effective control measures that provide the greatest reductions of those emissions of most concern.
- Refer to the most up-to-date USDA-NRCS conservation practice standards or guidance to ensure that implemented measures follow current guidelines.

For a summary of the potential emissions reductions associated with the measures included in this document, refer to Appendix A.1: Table of Mitigation Effectiveness for Selected Measures.

Using the Reference Guide

This technical guide identifies current USDA-NRCS approved and other demonstrated conservation measures that have been used to reduce emissions from animal production systems. The measures are categorized into six sections representing various aspects of livestock and poultry operations including: nutrition and feed management; animal confinement; manure management; land application; pasture and range management; and other supplemental practices. Additional information, including a list of state regulatory programs for animal feeding operations and links to more detailed descriptions of the conservation measures included in this guide, can be found in the appendices.

It should be noted that not all practices will be well-suited for every region or specific animal production operation. Thus, the conservation measures are designed so that producers will have options and flexibility in selecting the most effective practices for their operation.

This guide is intended to provide information on the potential mitigation of air emissions via USDA-NRCS approved and/or other demonstrated measures. However, many of these measures also provide co-benefits for other resource concerns that are not identified in the document. To learn more about co-benefits from the practices outlined in this guide, please consult your local USDA-NRCS State Office or the listed reference.

USDA-NRCS has developed conservation practice standards using scientifically-proven research and demonstration of technologies. For conservation measures described in this guide that have related practice standards, the USDA-NRCS Practice Codes are listed. Each of the conservation practice standards contains information on why and where the conservation practice is applied and set forth minimum criteria for implementing the practice that must be met during application to achieve the intended purpose(s). USDA-NRCS may be able to provide technical assistance to agricultural producers for implementing these and other conservation practices, and, in some cases, financial assistance may be available.

Each measure is organized to provide:

- ***Description***
- ***Additional Considerations*** *highlighting other factors related to each measure*
- ***NRCS Conservation Practice Standards*** *that include the measure*
- ***Additional Conservation Activities*** *listing state programs that include the measure*
- ***More Information*** *on resources that provide further detail about the measure*

State-specific versions of the conservation practice standards are available through the USDA-NRCS Field Office Technical Guide (FOTG) for each state. If no state conservation practice standard is available in the FOTG, please contact the appropriate USDA-NRCS State Office or local USDA Service Center. These offices are available to answer state and local questions and provide many forms of assistance. The locations of these offices can be found at the following websites:

USDA-NRCS State (and Local) Offices: www.nrcs.usda.gov

USDA Service Center Locator: http://offices.sc.egov.usda.gov

Additional Resources

USDA-NRCS has developed educational tools that are designed to provide information about air quality and are accessible to the public. To view these online courses please visit:

www.airquality.nrcs.usda.gov.

The EPA has developed a website that provides links to various agriculture and air quality related topics. For more information, please visit:

https://www.epa.gov/afos-air.

Section 1: Nutrition and Feed Management

Figure 1.1 Discussion of feed composition.

Nutrition and feed management measures can improve feed efficiency and manipulate the quantity and quality of available nutrients, feedstuffs or additives fed to animals, which can assist in managing the quantity of nitrogen (N), phosphorus, sulfur, salts and other nutrients in manure, thereby reducing particulate matter (PM) and gaseous emissions from animal feeding operations (AFO). Animal diets are a critical component of air emissions management on a livestock or poultry operation. Nutrients form the basis of many of the compounds that can be generated and emitted at various stages of the operation. Feed ingredients often serve as the initial input of nutrients into animal production systems, so managing the amount and form of nutrients supplied in the feed can be very effective in mitigating emissions throughout the whole animal production system. Reducing these nutrients up front leaves fewer nutrients that can potentially be emitted later in the operation. However, in most cases, being able to formulate a diet that exactly matches the maintenance, growth and production requirements of each animal is a challenge. Additionally, as feed costs are typically the single largest expense for many livestock and poultry operations, much emphasis is placed on least-cost feed formulation.

Animal diet ingredient forms and amounts affect the digestibility, nutrient retention capability and characteristics of nutrients excreted. Changes in diet formulation may lead to changes in animal manure chemical composition that eventually results in changes in air emissions. Traditionally, animals are fed to meet the nutritional requirements needed for the growth and performance goals of the animals with available feedstuffs. Because of the variability of nutrient contents in available feedstuffs, nutritionists will typically include a “safety margin” to guarantee that the nutrient requirements of the animals are met. Additionally, due to the availability and costs of feedstuffs, as well as the inherent variation in nutrient content in those available feedstuffs, certain nutrients may be in excess in the diet formulation in order to meet the minimum requirements for other nutrients. For example, a nutritionist may formulate a specific diet based on the limiting nutrient in the combination of available feedstuffs. However, given the quantities of other nutrients in the available feedstuffs, those other nutrients may be included at an amount greater than that needed to meet the nutrient requirements of the animals. Although it may sound like a simple solution to acquire feed ingredients that exactly match all nutrient requirements of the animals, producers are often constrained by the types and costs of available feedstuffs. Additionally, some producers, especially in integrated poultry and swine systems, may not have any control over their nutrition and feed regimen, as feed is often provided directly to the farm from the integrator.

Also, because each animal is unique with individual nutrient requirements and growth/production potential, formulating and delivering a diet to exactly match the nutrient requirements for each animal at each stage of its growth/production cycle is impossible with the technology presently available. Producers and nutritionists must categorize animals into groups based on various characteristics (e.g., sex, growth/production cycle) and develop diets to meet the needs of those particular groups. If the diet is formulated to the average animal in a particular group, the remainder of the group will be either overfed or underfed nutrients, depending on whether that animal is below or above average for the group. Likewise, formulating a diet to either the most productive or least productive animals in a group will result in overfeeding or underfeeding the remainder of that group, respectively. These inherent and unavoidable inefficiencies result in increased nutrient excretion (due to overfeeding) or reduced growth/performance (due to underfeeding).

Practices shown to be effective include group and phase feeding, changes in dietary formulation, inclusion of feed additives and proper storage, handling, processing and delivery of feed. Combinations of these practices can result in significant reductions in ammonia (NH_3), hydrogen sulfide (H_2S) and other emissions. One or more of the nutrition and feed management practices may be beneficial in mitigating air emissions. However, it is important that individual farms be allowed to select those practices that align with farm-specific infrastructure and production goals.

Conservation Measures:

- Group and phase feeding
- Dietary formulation changes
- Feed additives
- Feed processing, storage and delivery

➢ Conservation Measure: Group and Phase Feeding

Description

Figure 1.2 Supplemental feed pellets.

Animals of different sizes and sexes have different nutritional needs. Group and phase feeding practices involve separating animals by age or production state (phase), and/or by sex to provide diets that more closely match the different nutritional needs of each phase and sex to avoid providing excess nutrients in diets. Feeding animals a single diet over a long period of time will only meet the average needs of the animal over that time period, resulting in overfeeding of nutrients during parts of the period and underfeeding of nutrients during other parts of the period. More phases allow for better targeting of feed nutrient requirements but also result in greater effort and expense in formulating and delivering feed rations.

In swine production, producers frequently separate male and female pigs and feed them different diets to better fit the different growth rates and nutrient requirements of the two sexes. Using additional phase feeding throughout the life cycle can reduce NH_3 emissions and odors. In poultry production, phase feeding is also a common practice to reduce nutrient excretion and NH_3 emissions. Feeding broilers with additional phases (i.e., using six phases rather than four or fewer phases) and adding supplemental amino acids (as discussed in the *Dietary Formulation Changes* Conservation Measure below) has been shown to result in a significant reduction of NH_3 emissions. In cattle production, phase feeding has been shown to have benefits for both dairy and beef cattle.

Additional Considerations:

- Increasing the number of feeding phases or groups also presents logistical challenges in managing a greater number of animal groups and efficiently preparing and delivering the correct ration to each of those groups. These logistical and management challenges, such as scheduling feed mill equipment, feed trucks, labor, etc., may make it difficult or impractical to properly schedule feeding times and prepare multiple rations within a single operation.

NRCS Conservation Practice Standards

- Feed Management (592)

Additional Conservation Activities

- From Wisconsin Department of Natural Resources "Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin"
  - Animal nutrition and feed management-lactating dairy cows
  - Animal nutrition and feed management-poultry and swine
- From the draft San Joaquin Valley Air Pollution Control District "Best Available Control Technology (BACT) Dairy Operations"
  - Feeding
- From Idaho Department of Environmental Quality "Rules for the Control of Ammonia from Dairy Farms"
  - Animal nutrition
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
  - Nutrition

More Information

- eXtension – Air Quality in Animal Agriculture: "Diet and Feed Management to Mitigate Airborne Emissions"
- Iowa State University – Air Management Practices Assessment Tool (AMPAT)
- Washington State University – National Feed Management for Livestock and Poultry

➢ Conservation Measure: Dietary Formulation Changes

Description

Dietary formulation changes involve changes in feed ingredients or ration formulations to provide essential available nutrients to meet animal requirements while minimizing excess amounts of nutrients. It reduces amounts of dietary protein and/or minimizes overfeeding of sulfur and other nutrients in rations to match, rather than exceed, animal needs.

In animal diets, protein provides amino acids needed for growth, reproduction and milk or egg production. A common measure of protein content in animal diets is crude protein, which is typically calculated as a multiple of the total N content and can include non-amino acid forms of N. Lowering crude protein content can reduce N excretion and thus NH_3 emissions; however, reduction of crude protein can cause deficiency in certain amino acids that significantly affect animal performance. Therefore, supplemental synthetic amino acids must be added in rations with lower crude protein content. Selection of supplemental amino acids should be species-specific, according to animal genetics, age, sex and other factors. Commonly used supplemental amino acids are lysine, methionine and threonine, which usually can be added to feed without significant additional costs.

For non-ruminants (i.e., swine and poultry), reduction of crude protein can be accomplished by supplementing feed with amino acids. High-quality, reduced crude protein diets with appropriate supplementation of amino acids can effectively reduce N excretion and NH_3 emissions from swine and poultry operations without compromising animal productivity. In swine production, soybean meal is a typical crude protein source. Replacing soybean meal with amino acids (synthetic lysine, methionine, threonine and tryptophan) and corn can reduce NH_3 emissions, H_2S emissions and odors. Pigs fed lower crude protein diets with added amino acids can perform as well as those fed conventional corn-soybean meal diets with no added amino acids. In poultry production, lysine and methionine are two commonly used synthetic amino acid supplements to lower crude protein in poultry diets.

For ruminants (i.e., beef cattle and dairy cows), protein concentrations in the diet should be formulated to meet metabolizable protein (degradable and undegradable proteins) needs for growth and/or meat or milk production. Manipulating the crude protein and energy content (carbohydrate and fat) in the diet can enhance the availability of amino acids in the diet. Beef cattle need less protein toward the end of their growth period. Reducing crude protein in cattle diets at this point can reduce NH_3 emissions significantly. Some crude protein reductions may also be implemented for dairy cattle, but must be closely managed to avoid impacting productivity (e.g., milk yield, fat corrected yield, milk protein yield).

Additional Considerations:

- Nutrient concentrations in feeds and feed ingredients vary considerably. Moreover, not all nutrients in feed are equally available to animals. It is essential to obtain up-to-date information about the availability of nutrients in feed ingredients to formulate diets. Therefore, regular laboratory analysis of feed should be performed on feed ingredients and the formulated diets. However, additional analysis of feed and diets will also increase costs.
- Nutrient requirements vary based on animal genetics. Diets should be formulated for the specific animals to be fed.
- Feed costs are one of the most significant portions of the overall cost of animal production. Selection of readily-available and affordable feed ingredients may provide considerable logistical and economic challenges in formulating rations that more closely match animal requirements.
- Dietary formulation changes include various options that may be used to mitigate multiple gas emissions; however, supplementing diets with amino acids other than lysine, methionine or threonine may not be economically feasible.
- Supplementation with synthetic amino acids is most feasible in non-ruminant animal (i.e., swine and poultry) diets.
- The use of synthetic amino acids may not be compatible with some organic certification systems.
- Undesirable sulfurous compounds often originate from sulfur-containing amino acids and sulfur-containing mineral sources. Additionally, sulfur content of water supplies can

impact the generation of undesirable sulfurous compounds. Limiting unnecessary sources of sulfur can reduce emissions of H_2S and other volatile sulfur compounds.

- Byproducts such as wet or dry distillers grains with solubles (WDGS or DDGS, respectively) from ethanol production have gained popularity in recent years due to their increased availability and potentially lower cost as compared with traditional feed ingredients. However, these byproducts have variable nutritional content and should be analyzed carefully when added to animal diets. Ethanol production removes starch from corn and leaves a byproduct with high concentrations of crude protein, oil, fiber and minerals. DDGS and other byproducts can alter the nutrient availability of the feed and create nutritional imbalances. Adding wet distillers grains with solubles to cattle diets has been shown to increase manure slurry pH, odors and concentrations of NH_3, H_2S, phosphorous and sulfur.
- Dietary formulation changes generally increase feed costs due to the time and expense of diet formulation and new ingredient acquisition.

NRCS Conservation Practice Standards

- Feed Management (592)

Additional Conservation Activities

- From Wisconsin Department of Natural Resources "Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin"
    - Animal nutrition and feed management-lactating dairy cows
    - Animal nutrition and feed management-poultry and swine
- From the draft San Joaquin Valley Air Pollution Control District "Best Available Control Technology (BACT) Dairy Operations"
    - Feeding
- From Idaho Department of Environmental Quality "Rules for the Control of Ammonia from Dairy Farms"
    - Animal nutrition
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
    - Nutrition

More Information

- eXtension – Air Quality in Animal Agriculture: "Diet and Feed Management to Mitigate Airborne Emissions"
- Iowa State University – Air Management Practices Assessment Tool (AMPAT)

Conservation Measure: Feed Additives

Description

Many feed additives are regularly used to improve nutrient absorption from feed ingredients when added to animal diets. The additives can include various minerals, enzymes, antibiotics and other materials (e.g., beta-agonists, direct-fed microbials, metabolites). Improved nutrient absorption can improve nutrient utilization efficiency and reduce dietary nutrient content without compromising animal performance.

When minerals are used to meet dietary needs, caution should be taken to minimize some potential negative effects. Although trace mineral sources are a very small part of the diet and thus provide relatively little sulfur to the system, inorganic mineral sulfates can increase the formation and emission of sulfurous compounds. The mineral sulfate sources (zinc, iron, manganese and copper) in diets may be replaced with carbonate, oxide and chloride sources to reduce sulfur emissions. Moreover, organic mineral forms are usually more efficiently absorbed, minimizing the amount of additives needed and amount of minerals excreted, although these non-sulfate mineral sources may have lower mineral availability than mineral sulfate sources. Zeolite (i.e., clinoptilolite) has also been shown to adsorb nitrogen and reduce ammonia emissions from excreted manure when included as a feed additive.

In swine production, research has shown that adding small amounts of fiber (e.g., soybean hulls, sugar beet pulp, wheat bran) to the diet can reduce N excretion and lower the pH in swine manure. Lowering the manure pH can help prevent ammonium nitrogen in the manure from converting to NH_3 and thus reduce the potential for NH_3 emissions from the manure. Fiber sources, like soybean hulls, can reduce the proportion of N excreted in the urine, which reduces NH_3 emissions, while also reducing emissions of H_2S and odors. Other additives to reduce urinary pH for NH_3 reduction include calcium-salts, calcium-benzoate, a combination of phosphoric acid and calcium sulfate, and a combination of monocalcium phosphate, calcium sulfate and calcium chloride.

In poultry production, the primary strategy for changing pH of excreta in laying hens involves replacing some of the limestone in the diet with calcium sulfate (i.e., gypsum - up to one third of the limestone can be replaced without affecting bird performance or shell characteristics), although the addition of calcium sulfate increases the sulfur content of the diet. Replacement of dietary limestone with calcium sulfate, in combination with zeolite and slight reductions in dietary crude protein, may result in a reduction of NH_3 emissions, but at the expense of an increase in H_2S emissions. This is an example where prioritizing emissions reductions becomes important.

Additional Considerations:

- For all species, adding fat or oil to the diet can reduce PM emissions.

- Including feed additives generally increases feed costs due to the time and expense of diet formulation and feed additive acquisition.

NRCS Conservation Practice Standards

- Feed Management (592)

Additional Conservation Activities

- From Wisconsin Department of Natural Resources "Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin"
    - Animal nutrition and feed management-lactating dairy cows
    - Animal nutrition and feed management-poultry and swine
- From the draft San Joaquin Valley Air Pollution Control District "Best Available Control Technology (BACT) Dairy Operations"
    - Feeding
- From Idaho Department of Environmental Quality "Rules for the Control of Ammonia from Dairy Farms"
    - Animal nutrition
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
    - Nutrition

More Information

- eXtension – Air Quality in Animal Agriculture: "Diet and Feed Management to Mitigate Airborne Emissions"
- Iowa State University – Air Management Practices Assessment Tool (AMPAT)

➢ Conservation Measure: Feed Processing, Storage and Delivery

Description

Feed processing can impact nutrient availability and gas emissions. Fine grain particles have higher surface areas that allow digestive enzymes to break down the feed more easily and increase nutrient utilization. Decreasing feed particle size can increase dry matter and nitrogen digestibility and can lower the amount of nitrogen excreted in manure. The optimum particle size varies depending on the animal species. Creating pellets from feeds that have been ground into fine particles can allow producers

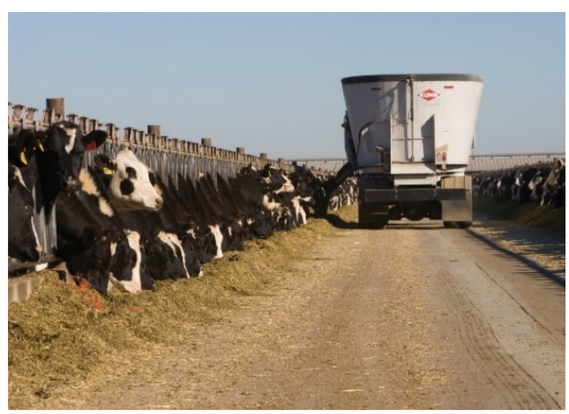

Figure 1.3 Feed delivery.

to improve nutrient utilization and also reduce feed waste by reducing the loss of feed ingredients as dust.

Proper feed storage can reduce spoilage. Spoiled feed and ingredients are subject to microbial decomposition, which can result in gaseous emissions. All dry feed should be stored in a dry place (e.g., grain bin, commodity buildings) or be covered. Silage piles and bunkers (storage areas for silage) should be covered to minimize feed spoilage. All feed unsuitable for refeeding should be removed from the site and disposed of in a suitable manner to minimize emissions caused by feed decomposition.

Feed delivery method and frequency can impact feed spillage. Spilled feed can end up in manure handling systems, increasing the carbon and nutrient loads to those systems. Improperly mixed feed or inconsistent feed deliveries can result in greater waste, which will add unnecessary feed expenses and increase the amount of material entering manure handling systems with commensurate increases in emissions from the manure.

Dust emissions from feed distribution systems for dry feeds can be mitigated with add-on PM control devices (e.g., cyclones and other inertial collectors, fabric filters) and passive measures, such as extended drop tubes for feed handling, thereby reducing PM emissions. Adding fat (1%), water (with a 3:1 ratio of water to feed) or “wet” feed ingredients, such as molasses, distillers solubles, or WDGS to dry feed rations can also reduce PM emissions. Using good feed bunk management practices (e.g., pushing feed that has been moved by the cattle back into the feed bunk, ensuring adequate feed bunk space per animal) with cattle can meet their feed intake needs and avoid excessive feed wastage.

Additional Considerations:

- Fine grinding can increase digestibility but can increase processing costs and dust emissions.
- Fine grinding has the potential to increase digestive disturbances, such as bloat, in finishing beef cattle.
- More intensive processing of feed and ingredients can increase energy use and costs.
- More intensive processing of feed may increase feed utilization, which can decrease the overall carbon footprint of the system.
- Reducing feed spoilage and loss via better feed storage, handling and delivery can result in lower costs associated with a reduction in feed losses.

NRCS Conservation Practice Standards

- Feed Management (592)
- Air Filtration and Scrubbing (371) – for dust emissions from feed distribution systems

Additional Conservation Activities

- From Wisconsin Department of Natural Resources "Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin"
  - Animal nutrition and feed management-lactating dairy cows
  - Animal nutrition and feed management-poultry and swine
- From the draft San Joaquin Valley Air Pollution Control District "Best Available Control Technology (BACT) Dairy Operations"
  - Feeding
- From Idaho Department of Environmental Quality "Rules for the Control of Ammonia from Dairy Farms"
  - Animal nutrition
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
  - Nutrition

More Information

- eXtension – Air Quality in Animal Agriculture: "Diet and Feed Management to Mitigate Airborne Emissions"
- Iowa State University – Air Management Practices Assessment Tool (AMPAT)

Section 2: Animal Confinement

Animal confinement systems vary with animal species, climate conditions and topography. Animals may be confined in buildings or in open corrals, pens and lots. Confinement systems can make it easier for producers to monitor and ensure animal health and well-being, manage feed to meet animal nutritional requirements and collect manure for storage and treatment.

Figure 2.1 A mechanically-ventilated production house with ventilation fans.

2.1 Buildings

Figure 2.2 A mechanically-ventilated swine finishing barn.

Figure 2.3 A hybrid-ventilation dairy barn.

Figure 2.4 A hybrid-ventilation turkey barn.

Livestock production conducted in buildings is intended to protect animals from predators, weather conditions and from the spread of diseases. Buildings can be naturally-ventilated, mechanically-ventilated or a hybrid of naturally- and mechanically-ventilated. Natural ventilation relies on wind flow to maintain temperature and/or provide pollutant removal in the building. Mechanical ventilation uses fan systems, usually with supplemental heating or cooling systems, for these purposes.

Natural ventilation is constrained by natural air flow through the building. Mechanical ventilation allows the producer to maintain air flow during those times when the wind is not blowing and allows for better environmental control (e.g., control of temperature, humidity and indoor air pollutants) to ensure animal health and well-being. However, mechanical ventilation also requires additional energy to operate the fans.

Buildings may enable farms to increase production efficiency, but they may also concentrate the emissions of air pollution from a smaller area and/or through vents. While this can increase localized levels of air emissions, it also offers opportunities to target emissions of pollutants to reduce the amount that is released to the atmosphere. Most modern poultry and swine production occurs in buildings, and other livestock species may also utilize buildings, depending on local climatic and operating conditions.

Conservation Measures:

- Litter amendments and manure additives
- Electrostatic precipitation
- Oil sprinkling
- Water sprinkling
- Biofilters
- Wet scrubbers
- Windbreaks/shelterbelts

➢ Conservation Measure: Litter Amendments and Manure Additives

Description

Litter amendments and manure additives primarily aim to address the generation of air emissions by changing manure properties (e.g., pH) to prevent gases from forming. While litter amendments are most often used to mitigate NH_3 generation from poultry litter, manure additives can help prevent generation of NH_3, H_2S and volatile organic compounds (VOCs) from manure of other animal types. Commonly used litter amendments and manure additive categories include: (1) chemicals (i.e., acidifiers); (2) adsorbents; and (3) biological compounds (i.e., microbes or enzymes).

Figure 2.5. Litter amendment application in a poultry house (image courtesy of Sanjay Shah, North Carolina State University).

Chemical additives reduce NH_3 production by lowering the pH to create slightly acidic conditions in poultry litter or swine manure. When conditions are acidic, less ammonium is converted to NH_3. Acidification of poultry litter is more common than acidifying slurry manure. In poultry production, especially broiler (meat bird) production, acidifiers are often applied to floors and/or litter between flocks. Common acidifiers used as poultry litter treatments include alum or aluminum sulfate, acidified clay (clay soaked in sulfuric acid), sodium bisulfate and ferric sulfate. The effectiveness of adding acidifiers for NH_3 prevention depends greatly on the type and application rate of the acidifier, litter age and moisture content. Acidifying slurry manure is not used as frequently because there is a potential that it will increase both the risk of foaming and the generation of H_2S. It can be difficult to apply the amount of acidifiers needed to completely treat manure and overcome its natural buffering capacity with chemical additives.

Adsorbents are biological or chemical materials with large surface area and the capability to physically or chemically bind gaseous compounds onto their surfaces to reduce gas emissions.

Zeolite (e.g., clinoptilolite, a crystalline silicate material found naturally) is one type of adsorbent that may chemically interact with ammonium ions to reduce NH_3 emissions from poultry litter or slurry manure (e.g., from swine or dairy). Sphagnum peat moss is another type of adsorbent that may be used to mitigate gas emissions in swine production. While adsorbents have good potential for gas emission control, evenly distributing the adsorbent solid materials inside the production houses is typically challenging.

Microbial additives are a mixture of microorganisms and/or enzymes added to the manure systems to break down the organic compounds, thus reducing emissions of NH_3, H_2S and other odorous gases. The performance of microbial additives varies depending upon the types of microorganisms and/or enzymes contained in them. However, it is often difficult to establish microbiological additives due to competition from naturally-occurring bacteria in manure.

Another “additive” is the use of an electrical charge to cause chemical changes in the manure treatment system (electrical conductivity and non-thermal plasma treatment). Electricity can be introduced into the manure itself or the gases from manure storages can be collected and treated in a non-thermal plasma generator system (e.g. pulse corona, silent discharge, surface discharge and packed bed reactors). These treatments have been successful at reducing H_2S, NH_3 and odor. However, they are both expensive, and the non-thermal plasma generator can produce carbon monoxide and ozone, which can be hazardous to animals and workers.

Selection of manure amendments or additives should be done with consideration for type of manure, gases of interest and final use of the manure. Additives are often temperature-, moisture-, and/or pH-dependent and these conditions can vary in manure treatment systems, decreasing the effectiveness of the additive. An additive may also require additional modifications to the manure storage to be effective, such as aeration or solids separation, which can add cost and complexity. Special caution needs to be taken in the selection of acidifiers as some may be toxic to animals. Additionally, some acidifiers may change the form or concentrations of phosphorus in either liquid or solid manure, which can be a concern for producers with strict phosphorus limits in their nutrient management plans and affect their ability to use the manure as fertilizer. It is important to consider the effect that an additive will have on other manure management and land application systems in place at the farm. For example, will the treated manure corrode or clog existing equipment? Does it still have an appropriate moisture content and pH for its intended uses? It is important to make sure that the additives do not shorten the useful lifespan of the manure storage structure or have their own objectionable odor. Overall, there have been many studies with varied results, many finding no success. While real-world experiences with additives have had varied results, an additive well-matched to site-specific conditions can be useful as part of a larger (more complex) strategy to reduce air emissions from an AFO.

Additional Considerations

- The use of amendments to reduce the generation of ammonia and other gases from manure in confined spaces may allow altered ventilation strategies at an appreciable energy savings. For example, during winter months, ventilation of ammonia and other emissions increases the amount of cold air that is brought into the building and must be heated. Therefore, reducing the generation of these gases allows producers to save on both ventilation system run time expenses and heating costs.
- Additives selected to control one source of emissions may impact other sources of emissions. For example, acidification may result in a large reduction of NH_3 and less reduction of methane (CH_4), but with a large increase in H_2S and a smaller increase in N_2O emissions.
- The effect of additives is reduced if they are not continually applied. If manure is treated with additives in the housing structure, treatment must continue in long-term storage if the manure is not immediately land-applied. Also, while treated manure may not release ammonia during storage in a combined storage and treatment system, it may begin to release ammonia again when it is land-applied and temperature and pH conditions change.

NRCS Conservation Practice Standards

- Amendments for Treatment of Agricultural Waste (591)

Additional Conservation Activities

- From Wisconsin Department of Natural Resources "Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin"
    - Binding ammonium-alum treatment of poultry litter
    - Chemical or biological manure additives
- From Iowa Department of Natural Resources "Animal Feeding Operations Technical Workgroup Report on Air Emissions Characterization, Dispersion Modeling and Best Management Practices"
    - Acidification
    - Additives
- From Pennsylvania State Conservation Commission Odor Management Program "PA Odor BMP Reference List"
    - Manure pit additives
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
    - Reduce the pH of lagoons and manure piles
    - Purple sulfur bacterial formation in lagoons
- From Idaho Department of Environmental Quality "Rules for the Control of Air Pollution in Idaho (IDAPA 58.01.01)"

- From Texas Agricultural Extension Service “Managing Nuisance Odor and Dust from Poultry Growing Operations”

More Information

- eXtension – Air Quality in Animal Agriculture: “Poultry Litter Amendments” & “Additives for Improving Hog Farm Air Quality”
- Iowa State University – Air Management Practices Assessment Tool (AMPAT)
- “Feasibility Study for Alternative Technologies and Utilization for Managing Dairy and Poultry Manure” by Wright-Penn for Connecticut Department of Environmental Protection
- Iowa State University and The University of Iowa Study Group “Iowa Concentrated Animal Feeding Operations Air Quality Study Final Report”
- Penn State Extension – “Manure Additive Shows Swine Odor Reduction”
- Virginia Cooperative Extension – “Ammonia Emissions and Animal Agriculture”

➢ Conservation Measure: Electrostatic Precipitation

Description

Figure 2.6. ESP used in a swine nursery (image courtesy of Matt and John Baumgartner, EPI Air).

Electrostatic precipitation (ESP) can be used to reduce PM (e.g., PM_{10}, $PM_{2.5}$) concentrations in animal production houses and the manure storage areas associated with housing systems, such as from manure storage areas underneath (poultry) layer houses. However, due to the variability among animal housing systems and the dynamic nature of such systems (e.g., housing structure variation, facility layouts, seasonal changes of ventilation rates and patterns in response to the changes of air temperature, manure management practices and unique PM characteristics, etc.), off-the-shelf industrial ESPs are generally not successfully used in animal production systems.

The ESPs applied in animal facilities are usually custom designed with negatively charged systems. When installed within the production houses, these ESP systems consist of stainless steel electrodes that are attached to a power supply at a low current level to ensure safety. The electrodes create a high-voltage negative corona discharge to induce charges to the PM particles to be collected. The ESP systems may also be installed at ventilation exhausts to reduce PM emissions.

Additional Considerations

- The use of ESPs within buildings can lead to accumulation of PM on interior surfaces, which is very challenging to remove.

NRCS Conservation Practice Standards

- Air Filtration and Scrubbing (371)

More Information

- Iowa State University – Air Management Practices Assessment Tool (AMPAT)

➢ Conservation Measure: Oil Sprinkling

Description

Sprinkling of vegetable oil in animal production areas has been demonstrated as an effective measure for PM mitigation within swine barns. With this practice, oil is sprayed into the air, and particles that stick to the droplets settle onto the building surfaces. Oil droplet size should be controlled to avoid aerosolizing the oil and creating a risk of inhalation by animals or workers. Likewise, droplets that are too large will settle too quickly to be effective and may produce slick surfaces that are hazardous to animals and workers. Oil can be sprayed manually or with automated spray systems. Vegetable oils that have been evaluated for effectiveness, safety and cost include crude canola, purified canola, flax, corn, sunflower and soybean oils. While this practice originated as a measure to reduce PM emissions, smaller reductions of H_2S and NH_3 emissions have also been observed with the use of oil sprinkling.

Additional Considerations

- While effective, this measure has proven to be generally unpopular due to excessive oil buildup on alley surfaces, which may cause slippery surfaces and become a safety concern. In addition, it is time consuming and difficult to clean the oil residue on the floor or building surfaces. Oil buildup also can result in a disinfection issue and can cause substantial degradation by fouling fan surfaces at louvers, intake surfaces and propellers.

NRCS Conservation Practice Standards

- Air Filtration and Scrubbing (371)

More Information

- Iowa State University – Air Management Practices Assessment Tool (AMPAT)
- MWPS AED-42: Sprinkling Oil to Reduce Dust and Odor in Swine Buildings

➢ Conservation Measure: Water Sprinkling

Description

Sprinkling or misting of water in animal production areas has been demonstrated as an effective measure for PM mitigation. Similar to oil sprinkling, water is sprayed or misted into the air inside the building causing interception and deposition of airborne particles, as well as adsorption and deposition of hydrophilic gases such as H_2S and NH_3. Droplets that are too large will settle too quickly to be effective, while droplets that are too small may evaporate before contacting particles and gases. Water can be sprayed manually or with automated spray systems.

Additional Considerations

- As with oil sprinkling, excessive water sprayed into a building may cause slippery surfaces and become a safety concern.

NRCS Conservation Practice Standards

- Air Filtration and Scrubbing (371)

➢ Conservation Measure: Biofilters

Description

A biofilter is an air filtration and odor mitigation system that channels building exhaust through a mixture of organic materials (e.g., compost, wood chips) that support microbial growth. An air distribution system distributes the pollutant-laden air from the building exhaust to the biofilter bed (media) where microorganisms living on the biofilter media break down the pollutant gases into carbon dioxide (CO_2), water and salts. Biofilters are an established conservation measure, having been used for over 20 years. Well-maintained biofilters can reduce PM, NH_3, H_2S and odor, but can produce nitrous oxide (N_2O). In order to reduce the potential for N_2O production, it may be necessary to remove NH_3 and other nitrogen-containing gases from the air flow prior to the biofilter.

Figure 2.7 A flat open bed biofilter.

Biofilters are most effective for reducing emissions of gaseous pollutants from mechanically ventilated structures, such as houses or manure storage facilities. Key factors affecting biofilter performance include: (1) moisture content of, and distribution in, the biofilter medium; (2) retention time (the amount of time the gases take to pass through the biofilter media); and (3) static pressure. It is important to keep the filter media wet (moisture content greater than 40%) to keep the microorganisms on the media actively breaking down the gases; however, higher moisture content can lead to leaching, resulting in a potential wastewater management issue. The longer the retention time, the better the treatment. However, increasing the retention time usually increases the system static pressure, which can compromise the ventilation system performance. Lower ventilation airflow may lead to heat stress in the production houses.

Figure 2.8 A vertical bed biofilter at a University of Minnesota research farm (image courtesy of Iowa State University).

It is typically not practical to treat all of the exhaust air during the summer when a large amount of ventilation flow is required to remove excessive heat from the production house. Using biofilters to treat a portion of the ventilation air is a more economical practice that mitigates a considerable portion of emissions with less energy use. However, biofilters can be used year-round to treat the pit ventilation air of swine production houses where there is a reduced need to control temperature.

Biofilters are typically designed for site-specific conditions in one of two main configurations: flat open bed or vertical biofilters. The flat open beds have traditionally been used, are easier to construct and generally cost less than vertical biofilters due to lower operational and maintenance requirements; however, they have larger footprints than the vertical biofilters. Vertical biofilters are more difficult to construct, and biological material can settle, causing air leaks, which will reduce the performance of the system. Vertical biofilters can be designed in multiple layers and/or to have a tapered design to reduce the effects of settling, but will have increased cost and operational and maintenance requirements.

Additional Considerations

- Careful design is needed to minimize the impact of biofilter static pressure on production house ventilation systems.
- Monitoring and maintenance of the filter media moisture is essential. Sprinklers or other wetting systems may be needed.
- Biofilter media will need to be replaced periodically.
- Prevention of both air leakage, as well as dust accumulation and air constriction in the media, are also needed to ensure effectiveness of the system performance.
- Biofilter leachate should be monitored and managed appropriately.

- Rodents and weeds have been a problem for some biofilters.
- Biofilters can reduce CH_4 emissions, but may increase N_2O emissions due to microbial conversion of filtered NH_3. N_2O can be mitigated by using a scrubber or other NH_3 removal technique prior to the biofilter.
- Installation of a biofilter may require additional expense via the replacement of existing ventilation fans in order to provide the necessary air flow, as well as the energy to overcome the added pressure drop.

NRCS Conservation Practice Standards

- Air Filtration and Scrubbing (371)

Additional Conservation Activities

- From Wisconsin Department of Natural Resources "Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin"
    - Biofilter
- From Iowa Department of Natural Resources "Animal Feeding Operations Technical Workgroup Report on Air Emissions Characterization, Dispersion Modeling and Best Management Practices"
    - Filtration and biofiltration
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
    - Scrub exhaust of enclosed waste containers
- From Texas A&M AgriLife Extension "Improving the Air Quality of Animal Feeding Operations with Proper Facility and Manure Management"

More Information

- Iowa State University – Air Management Practices Assessment Tool (AMPAT)
- eXtension – Air Quality in Animal Agriculture: "Biofilters for Odor and Air Pollution Mitigation in Animal Agriculture"
- The Iowa Department of Natural Resources Animal Feeding Operations Technical Workgroup Report on Air Emissions Characterization, Dispersion Modeling, and Best Management Practices
- University of Minnesota Extension – *Biofilter Design Information*
- Minnesota Pollution Control Agency – "Feedlot Air Quality Summary: Data Collection, Enforcement and Program Development" (Biofilters and Covers)

Conservation Measure: Wet Scrubbers

Description

Wet scrubbers can be used to reduce PM and gas emissions from mechanically ventilated animal production houses. Although sharing the same scrubbing principles, off-the-shelf industrial scrubbers typically are not applicable to animal production systems due to the dynamic changes of such biological systems (e.g., housing structure variation, changes in ventilation air flow rate/pattern in response to the changes of air temperature, manure management practices, unique PM characteristics). The wet scrubbers used in animal production operations are usually custom designed and use either water droplets or chemical (e.g., acidic) droplets to capture pollutants. Water is typically used to capture PM and chemicals are often recommended to control gases. However, water can also be used to control some hydrophilic gases like NH_3. While the use of water is less effective than chemical solutions, it can reduce the operational and maintenance requirements associated with the storage and handling of chemicals. Well designed and operated wet scrubbers can be very effective in removing PM, NH_3 and VOCs in the exhaust air stream. Factors affecting the effectiveness of scrubbers include scrubber configuration, number of stages, scrubbing liquid composition, liquid-to-air ratio and retention time.

Figure 2.9 Two-stage scrubber using water and an acidic solution developed by USDA/ARS.

Additional Considerations

- Although wet scrubbers are used effectively in multiple sectors for control of PM and other gases, their application to animal production systems may be limited because of the high cost for these technologies and their potential to compromise the ventilation air flow rate needed to control temperature in production houses to ensure animal health.
- Scrubber efficiency depends upon the configuration, number of stages in the scrubber, scrubbing liquid composition and retention time in the scrubber.
- Wet scrubbers can also require large supplies of water and special wastewater handling systems (that are not typical at animal production operations).
- Installation of a wet scrubber may require additional expense via the replacement of existing fans in order to provide the necessary air flow, as well as the energy to overcome the added pressure drop.

NRCS Conservation Practice Standards

- Air Filtration and Scrubbing (371)

Additional Conservation Activities

- From Wisconsin Department of Natural Resources "Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin"
  - Wet scrubber/bio scrubber

More Information

- Iowa State University – Air Management Practices Assessment Tool (AMPAT)
- eXtension – Air Quality in Animal Agriculture: "Wet Scrubber for Mechanically Ventilated Animal Facilities" and "Development of an Acid Scrubber for Reducing Ammonia Emissions from Animal Rearing Facilities"

➢ Conservation Measure: Windbreaks & Shelterbelts

Description

Windbreaks or shelterbelts are fairly well established for mitigation of the emission and transport of pollutants through various pathways. They can be either natural (e.g., intentionally designed row(s) of trees or shrubs in linear configurations) or artificial (e.g., a solid brick or hay bale wall). Windbreaks can be used to prevent generation of PM emissions by slowing wind over open surfaces and reducing the potential for wind erosion. Likewise, using upwind windbreaks can reduce exchange of fresh air over animal housing and manure storages, which can reduce the potential for gaseous emissions from these sources. When used to mitigate emissions from production houses or manure storages, downwind windbreak walls can intercept PM; slow airflow to allow PM to settle out; create air turbulence to enhance atmospheric mixing, dilution, or dispersion of the emission plume; and create a physical barrier to horizontal air flow to encourage vertical transport of emissions to reduce ground-level concentrations. When used to mitigate emissions at the farm level, windbreaks slow the wind and thus reduce the transport of emitted gases, PM and odor from the farm. A

Figure 2.10 An experimental windbreak wall installed at a swine house exhaust fan.

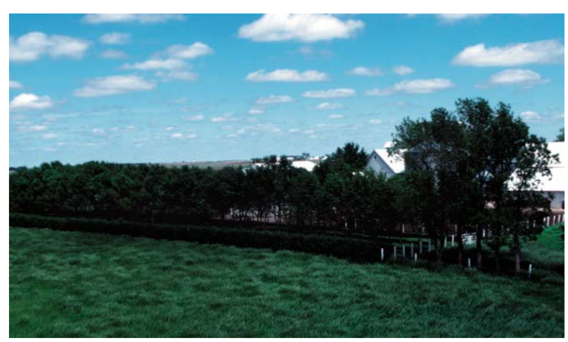

Figure 2.11 A shelterbelt (vegetative emission buffer).

windbreak will partially reduce wind speeds for a distance of roughly 30 times its height. Moreover, windbreaks promote mixing and dispersion of emitted gases and odor, which can lower pollutant concentrations at downwind locations through dilution.

The effectiveness of a windbreak depends on its placement, height, spacing and porosity. Windbreaks can be installed specifically to address the transport of emissions from individual systems (e.g., barns, lagoons, compost or manure piles) or near the property line to address the transport of emissions from the entire production operation. Also, while not a mitigation technique, the visual screen created by farm shelterbelts can help to reduce nuisance complaints by making the farm more visually appealing or less visible to passersby.

Additional Considerations

- Windbreaks, especially natural ones, may offer indirect benefits to animal production operations, such as enhancing the aesthetics of the operation, improving energy conservation by providing shade and/or reduction in wind loading and protecting livestock during windy winter conditions.

NRCS Conservation Practice Standards

- Windbreak/Shelterbelt Establishment (380)
- Windbreak/Shelterbelt Renovation (650)

Additional Conservation Activities

- From Wisconsin Department of Natural Resources “Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin”
    - Vegetative environmental buffer (VEB)
- From Iowa Department of Natural Resources “Animal Feeding Operations Technical Workgroup report on Air Emissions characterization, Dispersion Modeling and Best Management Practices”
    - Barriers
- From Yakima (WA) Regional Clean Air Agency “Air Quality Management Policy and Best Management Practices for Dairy Operations”
    - Land application-manure and/or chemical fertilizer: Installation of windbreaks or shelterbelts

More Information

- Iowa State University – Air Management Practices Assessment Tool (AMPAT)
- eXtension – Air Quality in Animal Agriculture: “Mitigating Air Emissions With Vegetative Environmental Buffers”

2.2 Open Lots, Pens & Corrals

In open feedlots and/or open corrals, pens not only serve as the animal housing system: they also function as the initial manure storage. In open animal production systems, pens are a primary source of emissions, which include fugitive PM, NH_3, VOCs and greenhouse gases (GHGs). The majority of finishing beef cattle and some dairy cows are housed in open feedlots and/or open pens. However, other species may also be housed in these types of systems.

Figure 2.12 Cattle in an open feedlot.

Conservation Measures:

- Pen surface management
- Manure additives
- Windbreaks/shelterbelts

➢ **Conservation Measure: Pen Surface Management**

Description

Proper management of pen surfaces is essential to minimize the generation and emission of air pollutants from these surfaces. Since most of these emissions are related to the accumulated manure on the pen surfaces and its subsequent decomposition, common practices include removing excess accumulated manure at periodic intervals, managing the moisture content of the accumulated manure on the pen surface or adding additional surface treatments to reduce the potential for emissions from the accumulated manure.

Figure 2.13 Sprinkler application of water to a feedlot pen.

Frequent manure harvesting may reduce the potential for generation of PM and gaseous emissions. Excess dry manure on the pen surface can be disturbed via animal activity and result in additional PM emissions. Excess manure on the pen surface also provides additional organic material for decomposition. In beef feedlot systems, manure is typically scraped and removed or compacted to assist in surface drainage approximately once per year or when the group of animals are removed from the pen. More frequent manure removal can reduce the volume of dry manure available to produce PM and gaseous emissions and also help in reducing the amount of moisture addition needed to properly manage pen surface moisture content.

Managing the moisture content of the accumulated manure on the pen surface can include promoting proper drainage and evaporation of water in wet areas and adding or promoting sufficient moisture in dry areas. Pen surfaces should ideally be well-compacted and sloped to promote proper drainage. Harrowing the in-pen manure to spread out the manure pack over a large area of pen surface and to encourage aeration can reduce the generation of gaseous emissions, but this action can produce PM emissions.

Several options are available for increasing the surface moisture content in dry areas of the pen surface. Sprinkler application of water can be an effective measure to add moisture and prevent fugitive PM emissions from pen surfaces. Excess amounts of dry manure on the pen surface reduce the effectiveness of this measure, as large amounts of water would need to be applied in those situations. Increasing the animal stocking density in the pen can also increase moisture addition via excretion from the animals. Providing shading in the pen will not only help to reduce heat stress in the animals but it can affect moisture addition by promoting better distribution of urine and feces over the pen surface as animals follow the shade during the day and by reducing the potential for evaporation in the shaded areas.

Other surface treatments can include the addition of bulk-type materials (e.g., mulch, straw, waste hay, sawdust, wood shavings) to the pen surface. These materials can help to dissipate energy from animal hoof action to reduce fugitive PM generation from open lot surfaces. Additionally, these materials can help to either soak up excess moisture from the manure pack or promote additional moisture retention on the pen surface and may also decrease NH_3 emissions. However, adding additional organic matter to the pen surface will also increase the amount of material that will be handled/moved during manure harvesting.

Additional Considerations

- The action of removing dry manure from the pen surface or harrowing surface manure also creates PM emissions. Conducting manure removal or harrowing activities under appropriate conditions (e.g., higher relative humidity, in the middle of the day when a higher solar angle will cause more heating and vertical atmospheric turbulence, etc.) can reduce downwind PM impacts.
- Care should be taken when removing manure from pens while animals are in the pens. Manure removal from pens while animals are in the pens can cause additional animal stress due to machinery operating in the pen, potentially resulting in decreased animal performance and health. Careful preparation, training and implementation of the activity is essential to avoid unnecessary stress on the animals.
- When removing manure from pens, more frequent removal is preferred in the feed bunks and loafing areas where manure deposition is the highest.
- When increasing animal stocking density to create additional moisture on the pen surface, care should be taken to avoid reducing per-head feed bunk space, as this has been shown to reduce animal performance. Additionally, increasing pen stocking

density can induce behavioral problems with the animals, leading to decreased performance and ability to handle the animals.

NRCS Conservation Practice Standards

- Dust Control from Animal Activity on Open Lot Surfaces (375)
- Mulching (484)

Additional Conservation Activities

- From Wisconsin Department of Natural Resources "Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin"
    - Open lots & corrals: open lot frequent cleaning (concrete and earthen surface)
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
    - Drylot pens
- From the draft San Joaquin Valley Air Pollution Control District "Best Available Control Technology (BACT) Dairy Operations"
    - Drylot confinement
- From Air Quality handbook for Conservation Management Practices for San Joaquin Valley-Minimizing Agricultural PM_{10} from Animal Feeding Operations (AFOs): Dairies and Feedlots
- From Idaho Department of Environmental Quality "Rules for the Control of Ammonia from Dairy Farms"
    - Open lots and corrals

More Information

- Colorado State University – Ammonia Best Management Practices (BMPs) for Livestock Operations
- Feedyard Dust Control in an Epic Panhandle Drought, 2010-2011 – Texas A&M AgriLife Research SP-417

➢ Conservation Measure: Manure Additives

Description

Chemical or biological litter amendments and manure additives can be used to manage air emissions from manure during its storage in open lots, pens and corrals by changing the properties of the manure that relate to emissions (e.g., pH). Refer to Section 2.1 for a more complete discussion of manure additives.

➢ Conservation Measure: Windbreaks/Shelterbelts

Description

Upwind windbreaks and shelterbelts can be used to reduce wind speeds over open lot or pen surfaces, reducing potential erosive effects of the wind as well as gas exchange above the pen surface. Downwind windbreaks and shelterbelts can be used to intercept and/or filter emitted PM and gases from open lots and pens or to increase dispersion of emitted contaminants to minimize downwind effects. Refer to Section 2.1 for a more complete discussion of windbreaks and shelterbelts.

Section 3: Manure Management

Manure is a common source of air emissions at animal feeding operations. Manure can be managed where it is generated, as it is collected and handled, during storage and as it is land-applied to reduce both the generation and the release of odors and gaseous emissions. Manure management systems vary depending on site-specific factors, such as the number and type of animals, local climate and land availability. Manure may either be managed as a solid or as a liquid/slurry and the storage of manure may be aerobic or anaerobic. While housing and land application are covered in other chapters, this section discusses measures that can be taken to reduce PM, NH_3, H_2S, VOC and GHG emissions during the collection and transport of manure from the animal housing (e.g., initial manure deposition) to the long-term manure storage and during storage itself. These measures range from practical management techniques to improved storage designs that minimize the generation, emission and transport of pollutants.

Air emissions from manure management systems fluctuate as various system parameters (e.g., moisture, temperature, pH) change. Techniques to manage emissions from manure systems typically require trade-offs that reduce emissions of some pollutants while increasing emissions of others. For example, maintaining a high moisture content can lower PM emissions and keep VOCs and NH_3 in solution but can increase emissions of odorous sulfur compounds and CH_4. Similarly, maintaining a high pH can decrease the potential for H_2S formation but increases the potential for NH_3 formation. Therefore, it is important to consider conservation measures related to manure management in the context of the overall goals for a particular livestock or poultry operation.

3.1 Manure Collection and Handling

Decomposition of manure begins as soon as it is excreted. As manure is collected, handled and temporarily stored prior to treatment, land application or other use, there are several measures that may be employed to reduce the potential for the generation or emission of air pollutants.

Conservation Measures:

- Solid-liquid separation
- Manure storage covers
- Biofilters
- Manure handling techniques

Conservation Measure: Solid-Liquid Separation

Description

The decomposition of manure solids during the anaerobic storage of liquid or slurry manures often causes odors and may lead to increased emissions of NH_3, VOCs, H_2S and CH_4. For manure streams handled as a slurry, separation of the solid and liquid portions prior to storage, additional treatment and/or land application may reduce odor and other gaseous emissions, particularly for undersized lagoons. Various solid separation technologies are used commonly for these purposes, including screens, rotary drums, centrifugal tanks, earthen pits, weeping walls, settling basins and screw-presses. There is a wide range of cost, effectiveness and energy usage between these various solid separation technologies, so selection of an appropriate separation technology is a site- and operation-specific decision.

Figure 3.1 Solid separation using an inclined screen separator.

Solid-liquid separation reduces the generation of odor and gases by reducing the load on manure treatment lagoons. Managing the separated solids to maintain low moisture content may minimize NH_3 generation and volatilization. In slurry manure streams, approximately 25% of the total N content is bound to the solids; however, actual emission reductions from liquid storages due to solids separation are not well-quantified.

Additional Considerations

- Solid-liquid separation creates an additional manure stream (manure solids) that also has a potential for emissions and must be managed.
- Solid-liquid separation does not work well for manure streams with very low or very high solids content, such as with some swine and poultry manure or manure from beef feedlots or dairy dry lots, unless advanced technologies or multiple separation stages or screen sizes are utilized to remove large and small solids from the manure stream separately.
- Dried separated solids may increase the potential for PM emissions, so proper storage and handling of these solids is recommended.
- Some separator designs may increase emissions of gases or particles during the separation process.

NRCS Conservation Practice Standards

- Waste Separation Facility (632)

Additional Conservation Activities

- From Pennsylvania State Conservation Commission Odor Management Program "PA Odor BMP Reference List"
  - Solids separation for manure
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
  - Manure solids separation
- From LSU Ag Center "Sustainable Dairy Production Best Management Practices" (Manure Management: Solid Separation) and "Environmental Best Management Practices for Louisiana Swine Production" (Manure Management: Solid Separation)
- From USDA-NRCS "Agricultural Waste Management Field Handbook"
  - Agricultural waste management system component design

More Information

- Iowa State University Extension – "Iowa Odor Control Demo Project: Solids Separation" Pm-1754i
- "Feasibility Study for Alternative Technologies and Utilization for Managing Dairy and Poultry Manure" by Wright-Penn for Connecticut Department of Environmental Protection (Liquid-Solids Separation)
- Iowa State University and The University of Iowa Study Group "Iowa Concentrated Animal Feeding Operations Air Quality Study Final Report"

➢ Conservation Measure: Manure Storage Covers

Description

Manure is often stored prior to land application – either as a liquid or slurry in open earthen basins or tanks or as a solid in stacks or piles. NH_3 and other gases are generated due to biological activity within the decomposing manure. Air exchange caused by wind passing over these storages is a source of emissions as pollutants are drawn by diffusion from areas of higher concentration (manure storages) to areas of lower concentration (fresh air). Additionally, the direct transport of PM and/or gases from these storages by the wind is another source of emissions. The use of a cover allows producers to significantly limit the release and transport of these emissions.

There are many different types of covers in use for manure storages, ranging from natural to synthetic, with varying degrees of complexity, availability and cost. Covers may be permeable or impermeable and flexible or rigid. The type of cover that is appropriate for each animal production operation depends on the size and type of manure storage, environmental factors and the goals of the producer. For example, concrete covers cannot be used on earthen or steel manure storages; natural covers are impractical if the surface area of the storage is very large due to high maintenance requirements; and geotextile/HPDE fabric covers are not recommended for storages that are frequently uncovered for various management practices (e.g., agitation or pumping).

Natural covers include (1) the crust that develops on some liquid manure storages and (2) fibrous mats, such as floating covers of chopped straw or other organic materials (barley, cornstalks), available on a farm. These covers are permeable, allowing rainfall to enter the storage, but slowing evaporation and emission from the surface. If a permeable cover is desired but organic materials are not readily available or require too much maintenance (e.g., chopping and re-applying straw), then synthetic options, such as clay balls (e.g., Leka rock) or geotextile materials (e.g., HDPE fabrics) may be used. These covers are more expensive than the natural options but have wider applicability and, typically, a longer life.

Figure 3.2 Maintenance of air vents on a manure storage cover.

Impermeable synthetic covers are the most effective covers for reducing the release of odors and other air emissions from manure storages. There are both flexible (plastic) and rigid (concrete, wood, fiberglass) options. Flexible covers can either float on the liquid surface or be inflated. Inflated flexible covers are at risk of damage by high winds. Rigid covers are more resistant to wind damage and other external loads but are generally the most expensive options for manure covers. As such, floating flexible covers are most commonly used while inflated flexible covers and rigid covers are not common. Regardless of the type of impermeable cover used, gases (e.g., CH_4) will collect under the cover and must be removed. Once collected, gases should be flared and/or otherwise utilized. Collected CH_4 can be used in various applications, such as boilers or engines, as a source of heat, energy and fuel.

Solid manure piles can also be covered to reduce PM, NH_3 and N_2O emissions and prevent moisture addition to the solid manure. Covers for solid manure piles can range from tarps or other flexible plastic covers to roofed manure storage buildings.

Additional Considerations

- Emissions mitigation effectiveness depends on the type of cover, with permeable biological covers being the least effective and impermeable synthetic covers being the most effective.

- Maintenance of covers, including replenishment of permeable covers, is very important in order to reduce emissions. The cost (both capital and ongoing) and time required for maintenance can be quite high, but greater reductions are generally achieved at higher costs.
- The use of covers creates anaerobic conditions in liquid manure storages, which leads to increased CH_4 generation. Additional steps (recovery of CH_4 for energy production, etc.) can be taken to destroy the CH_4, reducing overall GHG emissions.
- It is important to install a gas collection system with impermeable covers on liquid/slurry systems for safety and health concerns since some of the gases (e.g., CH_4) emitted from decomposing manure are explosive/flammable and others can be noxious, especially in high concentrations.
    - Gas escape ports or other ventilation methods are commonly used; however, some jurisdictions require more advanced equipment to capture and recover these gases so that they are not released to the atmosphere.
    - The use of covers can increase the potential for conversion of sulfur into H_2S and other sulfuric gases, which may cause corrosion issues in the gas collection and utilization system.
- Some applications for the use of captured gas require expensive refinement systems to clean and process the gas (e.g., use as vehicle fuel) and are not generally viewed as cost-effective.

NRCS Conservation Practice Standards

- Roofs and Covers (367)

Additional Conservation Activities

- From Pennsylvania State Conservation Commission Odor Management Program "PA Odor BMP Reference List"
    - Manure covers
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
    - Lagoon or storage covers
- From Colorado Department of Public Health and Environment Air Quality Control Commission "Regulation Number 2: Odor Emission (5 CCR 1001-4)"
- From Michigan Department of Agriculture and Rural Development "Generally Accepted Agricultural and Management Practices for Manure Management and Utilization"
    - Storages and acceptable covers
- From USDA-NRCS "Agricultural Waste Management Field Handbook"
    - Agricultural waste management system component design

More Information

- Iowa State University and The University of Iowa Study Group "Iowa Concentrated Animal Feeding Operations Air Quality Study Final Report"
- UMass Extension Crops, Dairy, Livestock, Equine "Conserving Ammonia in Manure"
- Minnesota Pollution Control Agency "Feedlot Air Quality Summary: Data Collection, Enforcement and Program Development" (Cover Technology)
- Clemson University Cooperative Extension "Dairy Training Manual"
    - Air quality and odor control from dairy production facilities

➢ Conservation Measure: Biofilters

Description

Biofilters, which channel air through a filter containing organic material (e.g., compost, sawdust) with an active microbial population, are commonly used to treat vented air from animal housing. However, biofilters can also be used to treat air vented from covered manure storages. Refer to Section 2.1 for a more detailed description of biofilters.

➢ Conservation Measure: Manure Handling Techniques

In addition to improving manure collection and storage methods to mitigate air emissions, some manure handling techniques may also result in reduced air emissions. Three major factors that affect potential air emissions from manure are temperature, moisture content and amount of oxygen. Low levels of oxygen favor the production of CH_4 and H_2S. Gaseous emissions tend to increase as temperature and moisture content increase. However, given the quantity of manure produced at animal production operations, there are practical limitations to the degree to which the temperature and moisture content of manure can be changed. Therefore, manure handling techniques vary depending on the existing condition of manure (e.g., liquid, slurry, solid) and focus on minimizing the generation of emissions from that manure.

Figure 3.3 Flushing to remove manure.

- **Manure Collection:** Remove manure from surfaces on which it collects as frequently as possible by flushing with water or scraping. Minimize the surface area on which manure collects and is stored. This reduces emissions by minimizing air transfer of pollutants from the manure to the surrounding atmosphere.
- **Liquid Storage:** Minimize exposed surface area. The decomposition of organic materials in liquid storages tends to occur under anaerobic ("without oxygen") conditions,

resulting in the generation of air pollutant gases. Remove settled solids or sludge properly as prescribed in the earthen basin and lagoon maintenance plan to help minimize excessive generation of these gases.

- **Solid Storage:** Minimize exposed surface area while maintaining aerobic conditions.
- **Prevent Rainwater Addition to Storages:** Minimize emissions by preventing the addition of rainwater to solid manure storages through the use of enclosures when practical. If not practical, ensure the cover adequately protects the entire solid manure pile and is secure against wind or other manipulation. Additionally, adjust the grade around the solid manure storage as necessary to prevent accumulation of rain water in the storage and to avoid uncontrolled runoff from entering the storage.
- **Storage Time:** Minimize the amount of time manure or litter is stored (before or in lieu of treatment) to prevent anaerobic conditions that often result in CH_4 and odorous gas emissions. In manure treatment or combined manure treatment and storage systems, ensure that manure is retained for at least the minimum recommended time to undergo treatment.

NRCS Conservation Practice Standards

- Waste Storage Facility (313)
- Waste Transfer (634)

Additional Conservation Activities

- From Colorado Department of Public Health and Environment Air Quality Control Commission “Regulation Number 2: Odor Emission (5 CCR 1001-4)”
- From Michigan Department of Agriculture and Rural Development “Generally Accepted Agricultural and Management Practices for Manure Management and Utilization”
- From Pennsylvania State Conservation Commission Odor Management Program “PA Odor BMP Reference List”
- From Rhode Island Department of Environmental Management/Division of Agriculture Best Management Practices “Barnyard, Manure and Waste Management”
- From Texas A&M AgriLife Extension “Improving the Air Quality of Animal Feeding Operations with Proper Facility and Manure Management”
- From USDA-NRCS “Agricultural Waste Management Field Handbook”
    - Agricultural waste management system component design

More Information

- Air Quality Handbook for Conservation Management Practices for San Joaquin Valley: Minimizing Agricultural PM10 from Animal Feeding Operations (AFOs) “Dairies and Feedlots” and “Poultry Operations”
- Iowa State University and The University of Iowa Study Group “Iowa Concentrated Animal Feeding Operations Air Quality Study Final Report”

3.2 Manure Treatment

Air emissions can be especially prevalent from long-term storage of manure, as decomposition of the organic material increases the emissions of NH_3, H_2S, VOCs and GHGs. Since these emissions can be sustained over a long period of time compared to the infrequent generation of emissions during activities such as agitation and land application, reducing emissions through the use of combined manure treatment and storage systems can have a significant impact on overall emission reductions from an animal production operation. A number of sophisticated technologies have been successfully used to decrease these emissions and related odors. While they are expensive, some of them result in improved manure products or marketable co-products that can return some revenue to the operation.

Conservation Measures:

- Oxygenation of Liquid Manure Lagoons
- Chemical and biological additives
- Composting
- Anaerobic digestion
- Thermo-chemical treatment

➢ Conservation Measure: Oxygenation of Liquid Manure Lagoons

Description

Lagoons that treat and store manure as a liquid or slurry can be designed as either anaerobic or aerobic lagoons. Many lagoons are often anaerobic because only a small amount of the manure is in contact with air. As the manure in the lagoon decomposes anaerobically, it releases CH_4, VOCs, NH_3 and H_2S. However, if sufficient oxygen is provided to the system, aerobic bacteria can thrive, which break down these organic compounds into simpler forms.

Aerobic lagoons can be designed with either natural or mechanical aeration. Naturally-aerobic lagoons are typically shallow and have a large surface area to increase contact with the atmosphere; however, this large land footprint is not practical for many farms. Mechanical aeration is commonly used in municipal and industrial wastewater treatment plants to eliminate almost all of the undesired air emissions by ensuring that oxygen is supplied evenly to all parts of the wastewater. However, the energy required at an animal production operation to introduce enough oxygen for complete aerobic treatment is very

Figure 3.4 Mechanical aeration of a manure storage.

expensive, so circulation and surface aeration are strategies that may be used to create an aerobic layer at the top of an anaerobic lagoon.

Circulation of manure can promote aerobic conditions in manure lagoons without the extensive energy requirements of complete aeration systems. It creates aerobic conditions by circulating the liquid in the lagoon such that it increases surface contact with the air and returns oxygenized liquid throughout the lagoon, minimizing the number of areas that may develop anaerobic "pockets." Systems that float on the lagoon surface and circulate the liquid and either force air down through the lagoon profile or bring liquid up to the surface for air exchange in order to mix and oxygenate beyond the top layer of a lagoon are now commercially available.

Figure 3.5 Aerobic circulator on a dairy lagoon.

Surface aeration focuses on creating aerobic conditions in the top layer of a lagoon to mitigate emissions as gases rise through the lagoon from the lower, anaerobic layers. Surface aerators can be fixed on or below the surface of the lagoon or float. Common technologies include low cascades, spray nozzles and submerged perforated pipes. While surface aeration will not completely eliminate odors and gaseous emissions from lagoons, it will reduce these emissions.

Additional Considerations

- Oxygenation is most effective in lagoons with low solids content. Besides requiring more energy for agitation and having a higher overall concentration of compounds that generate emissions while decomposing, lagoons with high solids content can experience more issues with equipment, such as clogged nozzles and pipes.
- It is also important to ensure that oxygenation through circulation or surface aeration is adequate to allow aerobic microbes to flourish. If it is too low, it may cause an increase in emissions by generating and "spreading" the gases generated by anaerobic decomposition instead of treating them.
- Natural oxygenation can be encouraged through lagoon design techniques so that agitation is not required; however, the large surface area and low loading rates required for these designs is not often practical for large animal production operations.

NRCS Conservation Practice Standards

- Waste Treatment Lagoon (359)
- Waste Treatment (629)

Additional Conservation Activities

- From Pennsylvania State Conservation Commission Odor Management Program “PA Odor BMP Reference List”
    - Aeration
- From Yakima (WA) Regional Clean Air Agency “Air Quality Management Policy and Best Management Practices for Dairy Operations”
    - Surface aeration of lagoons
- From Colorado Department of Public Health and Environment Air Quality Control Commission “Regulation Number 2: Odor Emission (5 CCR 1001-4)”
- From Michigan Department of Agriculture and Rural Development “Generally Accepted Agricultural and Management Practices for Manure Management and Utilization”
    - Treatment systems
- From USDA-NRCS “Agricultural Waste Management Field Handbook”
    - Agricultural waste management system component design

More Information

- Iowa State University and The University of Iowa Study Group “Iowa Concentrated Animal Feeding Operations Air Quality Study Final Report”
- Minnesota Pollution Control Agency “Feedlot Air Quality Summary: Data Collection, Enforcement and Program Development” (Aeration and Other Technologies)
- Clemson University Cooperative Extension “Dairy Training Manual”
    - Air quality and odor control from dairy production facilities

➢ Conservation Measure: Chemical and Biological Additives

Description

Chemical or biological litter amendments and manure additives can be used to manage air emissions from manure during its storage by changing the properties of the manure that relate to emissions (e.g., pH) or by acting as odor masks or perfume adsorbents themselves. Refer to Section 2.1 for a more detailed discussion of litter amendments and manure additives.

➢ Conservation Measure: Composting

Description


Figure 3.6 Compost windrows on California dairy farm.

Composting is a biological method of decomposition of manure in a controlled manner that involves maintaining specific carbon to nitrogen (C:N) ratios, moisture levels, temperature and aeration levels. Similar to the benefits of aeration for liquid or slurry manure, properly managed compost operations can reduce ammonia emissions and odors from solid manure. In addition to reduced odors and air emissions, composting can also reduce the microbial/viral/pathogen load in manure and destroy weed seeds. Finished compost is a stable product that can serve as a valuable soil amendment. However, composting requires supplemental energy to ensure proper aeration is maintained, either by forced air or turning the compost piles.

The moisture content and C:N ratio of a compost pile should be maintained within specific ranges to minimize odors and ammonia emissions while enabling active composting. Protecting the compost pile from wind and rain, such as by containing it in a vessel or covered building and building a windbreak around it, will reduce odors and potential air and water emissions.

In-depth information on composting design and application can be found in the references below.

Additional Considerations

- Increased levels of odor and H_2S, CH_4 and N_2O can be emitted if the manure pile becomes anaerobic, which is common in conditions with low temperatures, high moisture content and low aeration.
- If the C:N ratio is not high enough, NH_3 emissions can increase significantly.
- Low moisture conditions can lead to increased PM emissions.

NRCS Conservation Practice Standards

- Composting Facility (317)

Additional Conservation Activities

- From Pennsylvania State Conservation Commission Odor Management Program "PA Odor BMP Reference List"
    - Composting manure and other organic materials
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"

    - Properly manage the composting of stockpiled manure
- From Colorado Department of Public Health and Environment Air Quality Control Commission “Regulation Number 2: Odor Emission (5 CCR 1001-4)”
- From Michigan Department of Agriculture and Rural Development “Generally Accepted Agricultural and Management Practices for Manure Management and Utilization”
    - Composting
- Rhode Island Department of Environmental Management/Division of Agriculture Best Management Practices “Barnyard, Manure and Waste Management”

More Information

- NRCS *National Engineering Handbook* Part 637, Chapter 2 – Composting
- U.S. Composting Council Resources
- Cornell Waste Management Institute Composting page
- “Feasibility Study for Alternative Technologies and Utilization for Managing Dairy and Poultry Manure” by Wright-Penn for Connecticut Department of Environmental Protection
- Utah Division of Solid and Hazardous Waste Solid Waste Management Program “Composting Facility Guidance”

➢ Conservation Measure: Anaerobic Digestion

Description

Figure 3.7 Covered lagoon anaerobic digestion in California.

Anaerobic digestion (AD) is another process in which microorganisms break down manure, but unlike composting, AD occurs in the absence of oxygen. While AD occurs naturally in traditional manure storage and treatment lagoons under anaerobic conditions, it is usually incomplete and inefficient. By using a higher loading rate, incorporating mixing, heating the process and maintaining a consistent volume, anaerobic digestion will provide maximum odor reduction and other benefits. Covered lagoons or tanks with gas collection systems are most commonly used for AD, but a variety of specialized technologies exist, depending on the moisture content of the manure. When properly managed, AD yields a stable end product that is a valuable soil amendment with a reduced pathogen load. During AD, VOCs are converted into biogas, which is approximately 60% CH_4 and 40% CO_2, both of which are greenhouse gases. CH_4, along with H_2S formed during anaerobic conversion of sulfur in the digester, can be captured and destroyed. Although CO_2 is created by the destruction of the captured CH_4, this process results in an overall reduction in GHGs from the digester system. Overall systems can be designed to result in a net decrease of GHGs by focusing on CH_4 reductions at the expense of CO_2 increases, since the global warming impacts of CH_4 are more than 20 times greater than CO_2. Odors can be greatly reduced while volume and overall nutrient (nitrogen, phosphorus, potassium) levels remain the same. Much of the organic nitrogen is converted to ammonium during the digestion process. Thus, during post-digestion storage, NH_3 emissions from the digester effluent are increased compared to untreated manure.

Additional Considerations

- Anaerobic digestion is very expensive, both due to capital costs and ongoing operation and maintenance expenses.
- The captured gases can replace a variety of traditional electricity or fuel sources. The amount of additional treatment needed to refine the gas for different end uses varies from no/low refinement for use in boilers to sophisticated upgrades for use as vehicle fuel. Depending on the animal production operation's onsite needs and the local market for such products, these options may not be cost-effective in many areas of the country.
- New AD projects at livestock operations are eligible to earn carbon offsets in various emission trading systems and may generate credits that can be sold, creating additional revenue for a project.
- Additional NH_3 mitigation post-digester may be beneficial in $PM_{2.5}$ nonattainment areas and other areas near nitrogen-sensitive ecosystems.
- Some forms of energy conversion from biogas (e.g., burning biogas in an engine to produce electricity) may increase emissions of combustion-related pollutants, such as NO_x. This can be a significant factor in ozone nonattainment areas because NO_x is an ozone precursor.
- Although technologies for digesting solid manure streams are emerging, many of these systems require significant addition of water, which may not be feasible in water-limited areas.

NRCS Conservation Practice Standards

- Anaerobic Digester (366)
- Roofs and Covers (367)

Additional Conservation Activities

- From Pennsylvania State Conservation Commission Odor Management Program "PA Odor BMP Reference List"
    - Anaerobic digestion
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
    - Proper operation and maintenance of anaerobic digester

- From Michigan Department of Agriculture and Rural Development "Generally Accepted Agricultural and Management Practices for Manure Management and Utilization"
    - Anaerobic digesters

More Information

- EPA AgSTAR Program
- eXtension – "Farm energy anaerobic digestion and biogas"
- "Feasibility Study for Alternative Technologies and Utilization for Managing Dairy and Poultry Manure" by Wright-Penn for Connecticut Department of Environmental Protection
- Iowa State University and The University of Iowa Study Group "Iowa Concentrated Animal Feeding Operations Air Quality Study Final Report"
- Minnesota Pollution Control Agency "Feedlot Air Quality Summary: Data Collection, Enforcement and Program Development" (Aeration and Other Technologies)

➢ Conservation Measure: Thermo-chemical Treatment

Description

An emerging area of manure treatment involves the thermal conversion of manure and other biomass. While thermo-chemical technologies are not new, their application at animal production operations is fairly limited and quite expensive. There are three main classes of thermo-chemical technologies, depending on the amount of oxygen present in the treatment system: incineration (conducted in an oxygen-rich environment), gasification (conducted in a low oxygen environment), and pyrolysis (conducted in anaerobic conditions). These technologies are most applicable to dry or dried manures, such as poultry litter or feedlot manure. Solid/liquid separation is needed to partition the solid fraction of slurry manures before treatment using these technologies. All three technologies result in reduced total manure volume, but the products from each class of technology varies. Thermo-chemical technologies often require both federal and state permits, which are generally not cost-effective for an individual farm.

Incineration produces heat energy and an ash product. Although the ash product typically does not retain much of the nitrogen in the manure, it does retain the phosphorus and potassium from the manure and can be used as a valuable fertilizer. Incineration can emit many air pollutants, including NH_3, PM, NOx and other greenhouse gases; therefore, incinerators are regulated (i.e., generally need a permit or authorization prior to installation and operation) and require certain air emission controls. They also consume a great deal of energy and the cost of fuel can limit their applicability. In addition, sand and other inorganics commonly present in litter and manure can reduce performance of these systems.

Gasification produces a "syngas" (synthesis gas - similar to biogas and composed of approximately 30 to 60% carbon monoxide, 25 to 30% hydrogen, 0 to 5% CH_4, 5 to 15% CO_2 and a small amount of water vapor and other contaminants) that can be used for energy production and a char product. Gasification also drives off much of the nitrogen content in the manure, although phosphorus and potassium are retained in the char product, which can be used as a fertilizer. In addition, the process reduces GHG emissions and has a smaller footprint than anaerobic digestion systems. However, N in the manure is not retained in these systems and additional refinement of the syngas is often needed before the gas can be utilized, which reduces its cost effectiveness. Finally, sand and other inorganics commonly present in litter and manure can reduce performance of these systems as well.

Figure 3.8 Poultry litter gasifier.

Pyrolysis is similar to gasification, but occurs in an anaerobic environment and generates a bio-oil that has various uses, including energy production, in addition to syngas and char. The bio-oil may not be stable and its potential uses are limited without further refinement. Production rates can vary greatly between these systems and some N_2 is emitted.

Additional Considerations

- An additional benefit of thermo-chemical treatment is the destruction of pathogens in manure, which may increase the options for the final use of the resulting products.

NRCS Conservation Practice Standards

- Waste Treatment (629)
- Waste Gasification Facility (Interim 735)

More Information

- eXtension – "Thermal Manure-to-Energy Systems for Farms"

Section 4: Land Application

Figure 4.1. Conventional solid manure surface broadcasting.

The foundation of minimizing air emissions from land application begins with the appropriate management of nutrients using the "4R" nutrient stewardship concept. This concept is based on the "right source, right rate, right time and right place" of nutrient application; in other words, applying the correct amount of necessary nutrients to crops when they are most in demand and in a location where they are able to be accessed by specific plants. Excess nutrients that are not incorporated by plants or retained in the soil can become air emissions (the focus of this guide), surface runoff to local water supplies or groundwater recharge leachate. The most efficient way to minimize emissions is to avoid generating them by applying the 4Rs. However, the 4Rs will vary for individual animal production operations based on factors such as soil type, climate, farm size, crop type, manure handling, storage, treatment facilities, manure characteristics and management capability. Once the nutrients are balanced as closely as possible to the crop needs, producers can focus on additional management practices and specific application methods to further minimize the potential for emissions based on the types of crop (e.g., annual crops, perennial forage crops) receiving these nutrients.

Figure 4.2. Conventional liquid manure surface broadcasting.

Manure from animal production facilities is usually applied to fertilize crops on land. Solid manure (e.g., manure from poultry facilities, beef cattle feedlots) is typically broadcast onto the cropland surface using different types of tractor-pulled or truck-mounted spreaders that distribute the solid manure to the soil surface. Liquid and/or slurry manure (e.g., manure from swine, dairy production) is typically injected beneath the soil surface by a tractor-pulled tank wagon or dragline injection system to conserve nitrogen. However, broadcast application to the soil surface, sometimes followed by incorporation, is still used on some farms. Liquid manure is also applied via irrigation systems, such as center pivots or other sprinkler systems.

Applying manure to the soil surface without incorporation can lead to significant emissions of NH_3 and other odorous gases. Minimizing NH_3 emissions from land application practices can have a positive impact on the entire operation, not only by improving ambient air quality, but also by retaining more nutrients for crops that can reduce the need to purchase supplemental fertilizer. However, several of the management strategies for reducing NH_3 emissions from land application may lead to increased emissions of other gases, such as N_2O.

Conservation Measures:

- Associated Land Application Measures
- Injection
- Incorporation
- Banding
- Low pressure irrigation systems
- Subsurface application (e.g., drip irrigation)

➢ Conservation Measure: Associated Land Application Measures

Description

There are several recommended general management practices related to land application that producers can utilize to reduce air emissions, regardless of the specific method used to apply nutrients. These include: application according to agronomic recommendation, application below no-till residue and application under cool and calm weather conditions (timing).

Application of manure nutrients should always be made at agronomic rates with calibrated application equipment to avoid excess application that exacerbates nutrient losses. Agronomic application is the application of nutrients to meet crop needs, including the timing of those nutrient needs. Agronomic application rate is determined by knowing the nutrient content of the soil (soil test), the nutrient content of the manure (manure test) and the crop nutrient needs at the time of application (estimated or historical value). By matching crop needs to available nutrients, over-application of nitrogen can be reduced, which will minimize subsequent NH_3 and N_2O emissions. Additionally, applying nutrients in the spring prior to planting when crops are ready to utilize the nitrogen can also reduce NH_3 emissions compared to applying in the fall. Applying at lower soil temperatures can also help to reduce near-term NH_3 emissions due to reduced microbial activity in cooler soils. Split application of nutrients to better time nutrient application to crop needs can also be beneficial. A certified or trained nutrient management planner should be consulted to determine the agronomic rate and plan of annual applications to match crop needs.

The practice of no-till cropping is beneficial in reducing PM emissions from wind and water erosion, as well as increasing or maintaining soil health. No-till, where feasible, has many advantages, such as increasing soil carbon and water holding capacity. In these systems crop stubble commonly is left on the soil surface, creating a surface cover that helps protect against soil loss. However, when applying manure to high-residue systems, it is important to ensure that the manure application results in good manure to soil contact, as soil can bind to NH_3 and odorous compounds. Good manure to soil contact can be attained by applying the manure under the crop residue, not on top, or by partially mixing the manure into the soil by using vertical tillage implements (e.g., turbo-till) or mild incorporation that minimizes soil disturbance, such as shallow disk injection. These application techniques minimize disturbance of the soil, leaving sufficient surface residues to control erosion while decreasing NH_3 volatilization losses by limiting its exposure to ambient atmospheric conditions.

Temperature, humidity, wind speed and precipitation influence the rate of NH_3, PM and odor losses. NH_3 losses increase with rising temperatures and with greater wind speeds. Warmer temperatures shift the chemical equilibrium towards NH_3 gas (from ammonium). Besides the direct increases in volatilization due to higher wind speeds, these conditions also dry out the soil, which further compounds the potential for NH_3 loss as water is actively evaporating from the surface. The PM losses can also increase with higher temperatures and stronger winds due to the dry soil surface that can transport soil and manure particles from the surface into the ambient air, leading to higher ambient PM concentrations (primarily from PM_{10} and larger particles). Therefore, the application of manure during cool, calm weather with higher humidity will decrease the amount of PM emitted and NH_3 volatilized from the manure. Light precipitation events following application can also decrease NH_3 volatilization by binding NH_3 to soil clays.

NRCS Conservation Practice Standards

- Nutrient Management (590)

Additional Conservation Activities

- From Yakima (WA) Regional Clean Air Agency “Air Quality Management Policy and Best Management Practices for Dairy Operations”
    - Land application-manure and/or chemical fertilizer

More Information

- Iowa State University – Air Management Practices Assessment Tool (AMPAT)
- eXtension – Air Quality in Animal Agriculture: “Gaseous Emissions Following Land Application of Manures”

➢ Conservation Measure: Injection

Description

Injection of liquid and /or slurry manure is well known to significantly reduce several gaseous (e.g., NH_3, H_2S) and odor emissions as compared to traditional surface broadcasting, but can lead to additional emissions from increased denitrification activity (e.g., N_2O). Injection may be accomplished by using injectors (e.g., shanks, knives or covering disks) mounted on the application equipment to directly apply manure into the soil at a minimum depth of four inches.

Figure 4.3. Injection of liquid and slurry manure.

Manure injection should occur after crops have been harvested or before primary tillage. When injecting, caution should be taken when turning on end rows. If possible, manure should also be injected in the end rows. If manure remains on the field surface in the end rows, it should be incorporated as soon as possible. Effective manure injection means there should be little or no manure visible on the soil surface in the field.

Subsurface application of solid manure (e.g., poultry) is a newly developed technology from USDA-ARS that can mitigate ammonia emissions from land application by injecting solid manure into subsurface soil. While it has been demonstrated at full scale, the requisite equipment is not yet commercially available.

Additional Considerations

- Injection can cause an increase in GHG emissions, as manure injection can create anaerobic conditions in the soil that lead to N_2O emissions.
- Some types of injection may not be compatible with certain types of conservation tillage systems, such as no-till, due to increased soil disturbance. However, injection with minimal soil surface disturbance, such as shallow disk injection, is preferable to incorporation from a soil health and erosion perspective. Where normal management practices include zone-tillage or soil disturbance, injection is a preferred option.
- Injection requires additional equipment (e.g., injectors) and more horsepower, but may also increase nutrient retention for crops, positively impacting productivity. Therefore, site-specific economic factors should be evaluated when considering injection.

NRCS Conservation Practice Standards

- Nutrient Management (590)

Additional Conservation Activities

- From Wisconsin Department of Natural Resources "Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin"
  - Land application-injection
- From Iowa Department of Natural Resources "Animal Feeding Operations Technical Workgroup report on Air Emissions characterization, Dispersion Modeling and Best Management Practices"
  - Injection or incorporation
- From the draft San Joaquin Valley Air Pollution Control District "Best Available Control Technology (BACT) Dairy Operations"
  - Liquid manure injection
- From Idaho Department of Environmental Quality "Rules for the Control of Ammonia from Dairy Farms"
  - Soil injection of slurry
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
  - Inject or incorporate fertilizer within 24 hours of application

More Information

- Iowa State University – Air Management Practices Assessment Tool (AMPAT)
- eXtension – Air Quality in Animal Agriculture: "Gaseous Emissions Following Land Application of Manures"

➢ Conservation Measure: Incorporation

Description

Incorporation involves mixing manure or litter with surface soil at a minimum depth of four inches such that at least 80% of applied manure is covered with soil. Incorporation may be accomplished by using standard agricultural practices (e.g., tandem-disk tillage) or other equivalent practices that provide 80% soil coverage.

Figure 4.4. Injector unit, which can also be used as a shallow incorporation tool.

Broadcasting manure, either solid or liquid, without incorporation, results in the highest gas emissions. Ammonia, H_2S and VOC emissions can be reduced by incorporating manure through tillage immediately (or as soon as possible, but within 24 hours) after the manure has been applied. The effectiveness of this measure varies greatly, based on the amount of time between the initial application of manure and incorporation. In order to achieve significant rates of reduction, incorporation must occur within 1-2 hours of application. Moderate reductions can be achieved if manure is incorporated within 6-12 hours of application.

Additional Considerations

- Timing of manure incorporation is critical for the reduction of NH_3 emissions, with immediate incorporation leading to the greatest reduction. Incorporation should occur within 24 hours of surface broadcasting of solid manure. For liquid and slurry manure, manure should be incorporated immediately after land application using implements attached to the application equipment or, if possible, a second tractor operating behind the application equipment.
- Incorporation may not be compatible with certain types of conservation tillage systems, such as no-till, due to increased soil disturbance. However, it can be considered for operations where normal management practices include tillage or soil disturbance, including those with minimum tillage or reduced tillage.

NRCS Conservation Practice Standards

- Nutrient Management (590)

Additional Conservation Activities

- From Wisconsin Department of Natural Resources “Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin”
    - Land application - incorporation
- From Iowa Department of Natural Resources “Animal Feeding Operations Technical Workgroup Report on Air Emissions Characterization, Dispersion Modeling and Best Management Practices”
    - Injection or incorporation
- From the draft San Joaquin Valley Air Pollution Control District “Best Available Control Technology (BACT) Dairy Operations”
    - Liquid manure injection
- From Idaho Department of Environmental Quality “Rules for the Control of Ammonia from Dairy Farms”
    - Incorporation of manure within 24 hrs
    - Incorporation of manure within 48 hrs
- From Yakima (WA) Regional Clean Air Agency “Air Quality Management Policy and Best Management Practices for Dairy Operations”
    - Inject or incorporate fertilizer within 24 hours of application

More Information

- Iowa State University – Air Management Practices Assessment Tool (AMPAT)
- eXtension – Air Quality in Animal Agriculture: "Gaseous Emissions Following Land Application of Manures"

➢ Conservation Measure: Banding

Description

Band spreading, or banding, of manure involves the application of liquid manure in narrow bands either directly from a spreader hose or through a sliding shoe that rides along the soil surface. Banding allows relatively low-pressure manure application with less soil disturbance than incorporation. Reduced volatilization of gases from the low-pressure application results in reductions of NH_3.

Figure 4.5. Band spreading of manure.

A drop tube (or hose) spreader is a boom which has a number of hoses connected to it, distributing the liquid manure close to the ground in strips or bands. It is fed with liquid manure from a single pipe, relying on the pressure at each of the hose outlets to provide even distribution. Advanced systems use rotary distributors to proportion the liquid manure evenly to each outlet.

A drop tube or hose can be followed by immediate incorporation of manure using standard agricultural practices such as tillage, or other practices that are the equivalent, directly behind the tube or hose nozzle.

A trailing shoe/sliding foot spreader is similar in configuration to the drop tube spreader with a shoe added to each hose allowing the liquid manure to be deposited in narrow rows under the crop canopy onto the soil surface or just below the soil surface.

NRCS Conservation Practice Standards

- Nutrient Management (590)

Additional Conservation Activities

- From Wisconsin Department of Natural Resources "Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin"
  - o Land application-banding

- From Iowa Department of Natural Resources “Animal Feeding Operations Technical Workgroup Report on Air Emissions Characterization, Dispersion Modeling and Best Management Practices”
    - Injection or incorporation

More Information

- Iowa State University – Air Management Practices Assessment Tool (AMPAT)
- eXtension – Air Quality in Animal Agriculture: “Gaseous Emissions Following Land Application of Manures”

➢ Conservation Measure: Low Pressure Irrigation Systems

Description

This conservation measure involves the application of liquid manure using center pivot and linear move irrigation systems. These systems are adapted to operate at low pressures using drop nozzles. Larger droplets result in lower emissions because volatilization of gases is reduced due to the smaller surface area of the droplets. However, these larger droplets may cause infiltration problems on some soils. Low pressure application systems and sprinkler packages should not exceed 35 psi. This conservation measure can effectively reduce emissions of NH_3, H_2S and odor.

Additional Considerations

- Low-pressure overhead sprinklers and wheel lines do not qualify as Low Pressure Application (LPA) system technologies. Producers should consult with Certified Irrigation Designers and Nutrient Management Planners before converting non-LPA pivots and linear move systems.

NRCS Conservation Practice Standards

- Nutrient Management (590)

Additional Conservation Activities

- From Idaho Department of Environmental Quality “Rules for the Control of Ammonia from Dairy Farms”
    - Low energy/pressure application systems

More Information

- Iowa State University – Air Management Practices Assessment Tool (AMPAT)
- eXtension – Air Quality in Animal Agriculture: “Gaseous Emissions Following Land Application of Manures”

Conservation Measure: Subsurface Application

Description

For liquid manure, subsurface irrigation is a specialized irrigation method that allows for precise application of liquid to the root zone of the plant. Subsurface application systems require a specialized filtering system and "wastewater approved" drip lines to handle the solids content of the manure during distribution and prevent clogging. This measure can effectively reduce emissions of NH_3, H_2S and odor.

NRCS Conservation Practice Standards

- Nutrient Management (590)

Additional Conservation Activities

- From Idaho Department of Environmental Quality “Rules for the Control of Ammonia from Dairy Farms”
    - Subsurface drip irrigation

More Information

- Iowa State University – Air Management Practices Assessment Tool (AMPAT)
- eXtension – Air Quality in Animal Agriculture: “Gaseous Emissions Following Land Application of Manures”

Section 5: Pasture and Range Management

Grazing-based livestock operations are not normally perceived to be large sources of air emissions. However, the management of pastureland and rangeland does impact the emissions that are produced from these operations. Grazing lands, especially fertilized grazing lands, can result in substantial NH_3 emissions, although these emissions are typically less than those from confinement production systems. In grazing-based systems, pasture and range vegetation supply the majority of feed and nutrients to the animals and thus influence enteric emissions and excreted nutrients from the animals. Additionally, healthy vegetative cover on pasture and range can help to protect soil from wind erosion and can also sequester carbon from the atmosphere. Heavy-use areas where animals tend to concentrate, such as around shelter structures and watering facilities, can also see reduced vegetative cover and increased manure concentration. Reduced vegetative cover can result in an increase in erosion potential and increased manure concentration can result in manure-related emissions.

Figure 5.1 Pasture management using rotational grazing.

Conservation Measures:

- Improved vegetative and forage quality
- Management of animal congregation areas

➢ Conservation Measure: Improved Vegetative and Forage Quality

Description

Improving vegetation on pasture and range by promoting the desired vegetative species composition can have many positive impacts on reducing air emissions associated with grazing-based livestock operations. Adequate surface cover can help to lessen the potential for wind erosion and windborne PM emissions from pasture and range. Encouraging the production of above-ground and below-ground biomass can improve carbon sequestration. Maintaining higher residual vegetative heights as part of an overall grazing strategy can help to keep the ground cooler and damper, which can reduce NH_3 emissions. Additionally, promoting the growth and vigor of desired vegetative species can improve the quality and quantity of forage in range and pasture systems. Improved forage quality has a direct positive impact on feed conversion in grazing animals, resulting in less enteric emissions and decreased C excretion in manure.

The primary means that have been determined to improve vegetative and forage quality in pasture and range systems include using prescribed grazing, range planting and prescribed burning. Prescribed grazing adjusts the intensity, frequency, timing and duration of grazing and/or browsing by animals to meet the needs of the plant community or the nutritional needs of the animal. Rotational grazing systems are commonly used for these purposes. Prescribed grazing is typically accomplished by dividing pasture and range into multiple cells (or "paddocks"), each of which is grazed more intensively for a shorter period and then protected from grazing until its vegetative cover is restored. Range planting involves establishing perennial or self-sustaining vegetation, primarily on rangeland. Similarly, forage and biomass planting is used on pastureland. Prescribed burning is the application of controlled fire to a predetermined area in order to restore range ecosystem function and improve range plant production quantity and/or quality.

Additional Considerations:

- Although improved forage quality will improve N conversion in grazing animals, higher forage quality typically means higher protein content in the forage, which will tend to increase N excretion and NH_3 emissions.
- Application of prescribed burning can temporarily increase emissions of several pollutants (e.g., PM, NOx, GHGs, NH_3) during the burn. However, the improvement in vegetative and forage quality can result in reduced enteric fermentation in grazing animals, reduced PM emissions from wind erosion and improved carbon sequestration.
- Various tools (e.g., NUTBAL, GANLAB) have been developed to assist producers in monitoring nutrient concentrations in the diets and deposited manure of grazing animals. These tools can be used to inform grazing management.

NRCS Conservation Practice Standards

- Prescribed Grazing (528)
- Range Planting (550)
- Forage and Biomass Planting (512)
- Prescribed Burning (338)

Additional Conservation Activities

- From Wisconsin Department of Natural Resources "Beneficial Management Practices for Mitigating Hazardous Air Emissions from Animal Waste In Wisconsin"
    - Pasture – rotational grazing as production method
- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
    - Grazing management

More Information

- USDA-NRCS National Range and Pasture Handbook (2003)
- Center for Natural Resource Information Technology – NUTBAL: Nutritional Balance Analyzer (2011)
- Center for Natural Resource Information Technology – GANLAB: Grazing Animal Nutrition Lab (2011)

➢ Conservation Measure: Management of Animal Congregation Areas

Description

Areas of intensive animal use or congregation in grazing-based systems, such as near shelter, water sources or supplemental feed areas can provide an opportunity for damage to vegetation or the ground surface in those areas, as well as for increased manure nutrient concentration or accumulation. Reduced vegetation and ground surface damage can lead to PM emissions from wind erosion and increased manure accumulation can lead to greater manure-related emissions and nutrient concentrations.

Figure 5.2 Protection of an intensively-used area around a water trough.

Protecting intensively used areas with surface stabilization or treatment is an established measure to reduce the likelihood of wind erosion from permanent shelter and water sources. Periodically moving temporary shelter, water sources and supplemental feeding areas can also help to reduce intensive use and manure accumulation in those fixed areas. For irrigated pastures, appropriate irrigation immediately after grazing can help to incorporate deposited manure into the soil to reduce NH_3 volatilization potential.

NRCS Conservation Practice Standards

- Heavy Use Area Protection (561)
- Prescribed Grazing (528)

Additional Conservation Activities

- From Yakima (WA) Regional Clean Air Agency "Air Quality Management Policy and Best Management Practices for Dairy Operations"
  - Grazing management

Section 6: Other Supplemental Practices

In addition to the feed, housing, manure and other systems specifically related to animal production at agricultural operations, other processes at these operations can also affect emissions. These processes include animal mortality disposal areas, unpaved areas such as roads and equipment storage lots, and the stationary and mobile equipment used throughout a farm, from irrigation systems to tractors. Emissions include gases produced during animal decomposition, PM from dust and disturbed soil, and pollutants released via volatilization from chemical applications. Several techniques or modifications can be applied in these areas to reduce overall emissions from livestock and poultry production operations.

6.1 Mortality Management

Proper management of animal mortalities is critical to the biosecurity of farms but is also important to minimize the impact of the mortalities on air quality. While odor is of great concern, decomposing animal carcasses can also lead to emissions of NH_3, H_2S, CH_4 and other air pollutants. Several methods are effective at reducing air emissions from the disposal of animal mortalities.

Figure 6.1. Large carcass composting facility (image courtesy of Dale Rozeboom, Michigan State University).

Conservation Measures:

- Burial
- Landfill
- Incineration
- Rendering
- Composting

➢ Conservation Measure: Burial

Description

Burial is a very common method of disposing of carcasses, however it is not allowed in all jurisdictions. Most states have specific regulations governing animal burial that set limitations on site location, distance from waterways, depth to groundwater, number of carcasses and other factors. Some states only allow burial by specific contract companies at regulated sites. Federal regulations also apply in some instances, such as for carcasses contaminated with oil or other substances after an emergency or natural disaster.

Burial is safe if proper procedures are used, but may result in long decomposition times, especially in anaerobic environments. Burial can result in the release of fewer air emissions than incineration operations, depending on the additional control technologies employed by incinerators, and tends to be the most economical disposal method with the fewest design and operational requirements. It is commonly used to handle mass burial events, such as those following natural disasters or catastrophic disease losses. However, burial offers the least protection for groundwater and tends to promote anaerobic conditions, including emissions of H_2S and high odor levels.

NRCS Conservation Practice Standards

- Emergency Animal Mortality Management (368)

More Information

- eXtension – "Managing livestock and poultry mortalities"
- North Carolina State University – "Alternative Methods for the Disposal of Swine Carcasses" (ANS 01-815S)
- Texas A&M University – "Burial Methods and Disposal Practices for Plants and Animals"

➢ Conservation Measure: Landfill

Description

Another method of burial is the disposal of carcasses in a permitted landfill. Not all landfills routinely accept animal carcasses and there are significant fees associated with the disposal of carcasses in landfills. However, landfills are designed with sophisticated controls that provide increased protection for groundwater and that capture air emissions from the decomposing waste. Landfills may be more commonly used for mass burial events, such as those following natural disasters.

Additional Information

- If disposal of carcasses in landfills is allowed, consideration must also be given to on-site handling and transportation of the mortality, as well as additional bio-security measures.

NRCS Conservation Practice Standards

- Emergency Animal Mortality Management (368)

More Information

- eXtension – Managing livestock and poultry mortalities
- North Carolina State University – "Alternative Methods for the Disposal of Swine Carcasses" (ANS 01-815S)
- Texas A&M University – "Burial Methods and Disposal Practices for Plants and Animals"

➢ Conservation Measure: Incineration

Description

Incineration involves the quick and complete consumption of carcasses by fire and heat. While sophisticated designs of incinerators are commonly used in other sectors (e.g., disposal of municipal waste), incineration is often limited to much smaller equipment for small carcasses at animal production operations. Section 3.2 contains a detailed discussion of incineration and associated emissions. With regards to carcass disposal, incineration offers additional biosecurity benefits for animal production operations.

NRCS Conservation Practice Standards

- Animal Mortality Facility (316)
- Emergency Animal Mortality Management (368)

More Information

- eXtension – “Managing livestock and poultry mortalities”
- North Dakota State University – “Animal Carcass Disposal Options”

➢ Conservation Measure: Rendering

Description

Rendering is a process that uses high temperature and steam to convert waste animal tissue into value-added materials. While the process is not very complicated, there are very few rendering facilities across the U.S. and the associated fees at these facilities can vary. Factors that should be considered include availability of and distance to rendering facilities, cost, transportation and potential for bio-security breaches when compared to other available methods.

NRCS Conservation Practice Standards

- Emergency Animal Mortality Management (368)

More Information

- eXtension – “Managing livestock and poultry mortalities”
- North Dakota State University – “Animal Carcass Disposal Options”

➢ Conservation Measure: Composting

Figure 6.2. In-house composting of poultry mortality (image courtesy of Josh Payne, Jones-Hamilton Co.).

Description

As discussed in Section 3, composting can also be used to manage animal mortalities. The practice is well-established for poultry, swine and cattle carcasses. Composting is not appropriate for animals infected with prion diseases, such as bovine spongiform encephalopathy ("mad cow disease") in cattle or scrapie in goats and sheep. Due to the prevalence of scrapie in goats and sheep, composting is not generally used for these animals.

NRCS Conservation Practice Standards

- Animal Mortality Facility (316)
- Emergency Animal Mortality Management (368)

6.2 Unpaved Roadways and Other Areas

Figure 6.3 Dust from unpaved roadways.

Roadways and farmstead areas that are unpaved or not covered with some type of vegetation or other material (e.g., straw, wood chips) can generate airborne soil particles. This includes roads, traffic areas, parking lots, staging or assembly areas, equipment storage lots, runways and loading/unloading areas of farms and ranches. Vehicular action on parental material (e.g., soil, rock) causes mechanical fracture (e.g., crushing) into smaller particles that can become airborne. These unpaved areas can also produce dust by natural disaggregation of the parent material when wind acts upon them—though typically wind-eroded particles are larger than those produced by vehicular action.

The principal means of preventing dust generation is via the use of dust suppressants. These are substances applied to unpaved roads and other areas that bind together soil, gravel, dust particles and other materials. Suppressants can be very effective in reducing or eliminating the generation and suspension of PM. Another effective method of reducing PM is by controlling the frequency, duration and intensity of mechanical action on unpaved roads and other areas via controls on vehicular actions. Finally, if PM is generated from unpaved roads and surfaces on farms and ranches, vegetation can be used to intercept it and retard its transport into adjoining lands.

Regions of the U.S. where extended dry conditions occur and where there is an abundance of unpaved farm roads and surfaces are the most likely places where this issue will be prevalent. This includes much of the western U.S., the High Plains and areas with erosive soil types.

Conservation Measures:

- Dust suppressants
- Vehicular controls
- Vegetation controls on wind and dust interception

➢ Conservation Measure: Dust Suppressants

Description

Dust suppressants, or palliatives, come in many forms and can vary greatly in PM control effectiveness and longevity. Suppressants such as water are typically effective for only a short period of time (hours to a day or two), while biologically-based products like lignosulfonate have longer lifetimes, and petroleum-based products (like heavy road oil) can have lifetimes of a year or more.

Figure 6.5 Water application to an unpaved surface.

A primary USDA-NRCS conservation practice that can be used for this purpose is *Dust Control on Unpaved Roads and Surfaces*. This practice describes various means of controlling unpaved road and surface dust using some type of suppressant. Results from the utilization of this practice vary according to the suppressant used, but may result in PM reductions from 50% to 99% over the untreated case. Cost and environmental impacts are considerations in suppressant choice. Long-term cost-benefit analyses typically inform landowner decision-making. For instance, water may be the cheapest single-application alternative, but due to the need for repeated applications and associated costs of pumping and water application, as well as the potential cost of water rights in some parts of the U.S., it may be cost-prohibitive for long durations and frequent applications. In addition, water may simply be unavailable in arid regions and/or during droughts. There may be environmental impacts of all other suppressants, including salts and petroleum products, and these impacts should be considered when making dust control decisions.

Additional USDA-NRCS practices that may also be used for PM emissions control on unpaved areas include *Sprinkler System, Heavy Use Area Protection* and *Mulching*. These practices can be used to provide surface protection and cover to unpaved areas, thus making them less susceptible to erosion.

NRCS Conservation Practice Standards

- Dust Control on Unpaved Roads and Surfaces (373)
- Sprinkler System (442)
- Heavy Use Area Protection (561)
- Mulching (484)

Additional Conservation Activities

- From San Joaquin Valley Air Pollution Control District Agricultural Air Quality Conservation Management Practices:
    - Chips / mulches, organic materials, polymers, road oil and sand
    - Gravel
    - Paving
    - Water
- From Arizona Guide to Agricultural PM_{10} Best Management Practices:
    - Aggregate cover
    - Synthetic particulate suppressant

➢ Conservation Measure: Vehicular Controls

Description

Control of both the speed and frequency of vehicular movement on roadways and other areas is also an effective strategy for PM control. The USDA-NRCS conservation practice *Access Control* can promote PM emission reductions by restricting vehicle access to certain areas. Additional activities that can result in reductions in PM emissions are enforcement of posted speed limits, speed controls directly applied on engine components of vehicles/farm machinery, reduction of vehicular movement via combining operations and other methods for reducing vehicle travel on roadways and other areas, such as precision guidance systems. In addition, PM can be generated from soil transported from unpaved areas onto hard-paved surfaces that is then disaggregated and can become airborne by vehicular action on the paved road. Reducing this "track-out" of soil (via mud on tires and other vehicle surfaces) onto hard-surfaces can thus be an effective PM control strategy.

Figure 6.5 Speed limit for dust control.

NRCS Conservation Practice Standards

- Access Control (472)

Additional Conservation Activities

- From San Joaquin Valley Air Pollution Control District Agricultural Air Quality Conservation Management Practices:
  - Combined operations
  - Mechanical pruning
  - Restricted access
  - Speed limits
  - Track-out control
- From Arizona Guide to Agricultural PM_{10} Best Management Practices:
  - Access restriction
  - Reduce vehicle speed
  - Track-out control system

➢ Conservation Measure Description: Vegetation Controls on Wind and Dust Interception

Description

Reductions in PM emissions may also be achieved by intercepting airborne particulates via vegetative barriers and using conservation practices such as *Windbreak/Shelterbelt Establishment* or *Critical Area Planting*. However, dust control is best accomplished by preventing its initial generation. Vegetation placed along an unpaved roadway or other area can help contain and capture dust and prevent its transport away from the roadway area. In addition to the two conservation practices mentioned above, this also may be accomplished by following one or more of these additional practice standards: *Field Border, Hedgerow Planting, Herbaceous Wind Barriers* or *Tree/Shrub Establishment*. Care must be taken to apply the proper vegetation to withhold the expected dust load (especially on younger plantings) and do an effective job of intercepting the dust. A more complete description of windbreaks/shelterbelts can be found in Section 2.1.

NRCS Conservation Practice Standards

- Windbreak/Shelterbelt Establishment (380)
- Critical Area Planting (342)
- Field Border (386)
- Hedgerow Planting (422)
- Herbaceous Wind Barriers (603)
- Tree/Shrub Establishment (612)

Additional Conservation Activities

- From San Joaquin Valley Air Pollution Control District Agricultural Air Quality Conservation Management Practices:
  - Wind barrier
- From Arizona Guide to Agricultural PM_{10} Best Management Practices:
  - Artificial wind barrier
  - Critical area planting
  - Tree, shrub or windbreak planting

6.3 Equipment Modifications

Figure 6.6 Irrigation system pump.

Combustion systems (e.g., engines and other combustion devices) are integral parts of many types of equipment used in livestock operations. This includes both mobile equipment (e.g., tractors, trucks, loaders, harvesters) and stationary equipment (e.g., irrigation pumps, digester engines, heaters, boilers). These systems use fuel, combust it (with oxygen), produce heat and then convert that energy into mechanical motion for mobile equipment movement or for powering equipment attached to stationary engines. If combustion is complete (perfect) the by-products are just water and CO_2. However, combustion is never complete and other emissions are released, including NO_x, PM and VOCs. Various types of modifications to these engines can help to prevent or mitigate air emissions.

In addition to combustion, the normal operation of some agricultural equipment can release additional emissions, such as during harvesting or pesticide application. Since the emissions addressed by engine/equipment modifications are typically episodic (related to equipment operation more so than geography or meteorological conditions), the use of engine/equipment modifications may be appropriate in any area where agricultural emissions are contributing to an air quality issue. Equipment modifications can be a broad array of simple or sophisticated changes and can include new equipment, manufacturer options and independently-customized alterations.

Conservation Measures:

- Combustion equipment replacement/retrofit and operation
- Non-combustion equipment changes/technology improvements

➢ Conservation Measure Description: Combustion Equipment Replacement/Retrofit and Operation

Description

Uncontrolled, older and/or less efficient combustion equipment typically has higher air emissions (especially for PM and NOx) than controlled, newer and/or more efficient combustion equipment.

Replacing higher-emitting combustion units with lower-emitting or non-combustion alternatives can result in significant air quality improvement, as well as possible energy savings. Also, retrofitting existing combustion units with air emission controls or new technologies to improve combustion efficiency can reduce the amount of air emissions from the units.

Proper maintenance and operation is very beneficial to minimizing emissions from existing combustion equipment, as well as ensuring the equipment performs as it was originally intended. The load on the engine is reduced when equipment is operating at maximum efficiency, which can result in decreased engine operation time and thus less PM emissions. In some cases, making energy efficiency improvements can also result in decreased fuel use in combustion equipment and/or decreased combustion emissions.

The USDA-NRCS *Combustion System Improvement* and *Pumping Plant* conservation practices may be used if agricultural combustion systems and/or related components or devices are replaced or retrofitted for air quality and energy efficiency improvement.

NRCS Conservation Practice Standards

- Combustion System Improvement (372)
- Pumping Plant (533)

Additional Conservation Activities

- From San Joaquin Valley Air Pollution Control District Agricultural Air Quality Conservation Management Practices:
    - Irrigation power units
    - Conservation irrigation

➢ Conservation Measure Description: Non-combustion Equipment Changes/Technology Improvements

Description

Agricultural equipment changes and technology improvements for reducing air emissions can take many shapes and forms. These can include relatively simple fixes, like using a shield or deflector to knock particulates out of an airstream before they are released, or using lower-pressure pesticide application nozzles to limit volatilization and chemical drift. These can also include more advanced techniques, like making internal design changes to harvesting equipment to separate and deposit residue and dust prior to entrainment. Other examples include utilizing water spray bars and variable rate or targeted pesticide applicators.

NRCS Conservation Practice Standards

- Integrated Pest Management (595)
- Field Operations Emissions Reduction (376)

Additional Conservation Activities

- From San Joaquin Valley Air Pollution Control District Agricultural Air Quality Conservation Management Practices:
  - Equipment changes/technological improvements
  - Application efficiencies
- From Arizona Guide to Agricultural PM_{10} Best Management Practices:
  - Equipment modification

Appendices

Appendix A.1: Table of Mitigation Effectiveness for Selected Measures

Measure	Category	Target	PM	NH_3	H_2S	VOCs	GHGs	USDA-NRCS Practice
Group and Phase Feeding	Nutrition and Feed Management	Generation	---	15-45%	---	---	---	Feed Management (592)
Feed Additives	Nutrition and Feed Management	Generation	---	20-70%	30%	---	---	Feed Management (592)
Feed Processing, Storage & Delivery	Nutrition and Feed Management	Generation	---	20%	---	---	---	Feed Management (592)
Dietary Formulation Changes	Nutrition and Feed Management	Generation	50-80%	30-50%	30-50%	---	---	Feed Management (592)
Litter Amendments and Manure Additives	Animal Confinement Manure Management	Generation Emission	---	0-85%	0-80%	10-40%	0-60%	Amendments for Treatment of Agricultural Waste (591)
Electrostatic Precipitation	Animal Confinement	Emission	30-80%	---	---	---	---	Air Filtration and Scrubbing (371)
Oil Spray/ Sprinkling	Animal Confinement	Emission	60-85%	0-30%	20-30%	---	---	Air Filtration and Scrubbing (371)
Biofilters	Animal Confinement Manure Management	Emission	80%	45-75%	80-95%	70-90%	---	Air Filtration and Scrubbing (371)
Wet Scrubbers	Animal Confinement	Emission	60-90%	70-90%	---	50-90%	---	Air Filtration and Scrubbing (371)
Windbreaks and Shelterbelts	Animal Confinement	Transport	50-70%	---	---	---	---	Windbreak/Shelterbelt Establishment (380) Windbreak/Shelterbelt Renovation (650)
Manure Storage Covers	Manure Management	Emission	---	50-95%	50-80%	---	30%	Roofs and Covers (367)
Solid-Liquid Separation	Manure Management	Generation	---	0-10%	0-20%	---	---	Waste Separation Facility (632)
Oxygenation of Liquid Manure Lagoons	Manure Management	Generation Emission	---	-20-70%	-10-70%	---	---	Waste Treatment (629)
Composting	Manure Management	Generation Emission	-10-30%	-10-10%	30-70%	10-60%	10-60%	Composting Facility (317)
Anaerobic Digester	Manure Management	Generation Emission	---	-50-30%	0-10%	60%	80-85%	Anaerobic Digester (366) Roofs and Covers (367)
Timing of Land Application	Land Application	Generation Emission	---	65-70%	---	---	50-70%	Nutrient Management (590)
Injection	Land Application	Generation Emission	---	70-90%	50-75%	87%	---	Nutrient Management (590)
Incorporation	Land Application	Generation Emission	---	20-90%	50-75%	80%	---	Nutrient Management (590)
Banding	Land Application	Generation Emission	---	30-40%	---	---	---	Nutrient Management (590)
Stocking Density	Pasture and Range Management	Generation Emission	80%	---	---	---	---	Prescribed Grazing (528)

The effectiveness of the measures presented in this document depends on site-specific conditions that vary widely across livestock operations. Additionally, reductions of individual air pollutants have not been studied or quantified for every measure presented. This table provides a summary of the mitigation effectiveness available for measures in this document, largely based on the literature review conducted for the Air Management Practices Assessment Tool, which included examination of 265 papers on the mitigation of PM, NH_3, H_2S, VOC, GHG and odor emissions.[1] Although not comprehensive, this summary table provides examples of the ranges of expected emissions reductions from applying a specific conservation measure (in isolation). Note that these values do not reflect the potential emission reduction at the farm level, as the impact on overall emissions will vary based on a combination of factors specific to that operation. Additionally, not all of the emission reductions that have been observed in agricultural studies of the conservation measures have been quantified. Refer to the text for each measure for a broader discussion of potential emissions impact and tradeoffs.

Measures for which no agricultural specific emission reduction values were found include: pen surface management, thermo-chemical treatment, low pressure irrigation systems, subsurface application, improved vegetative and forage quality, mortality management, dust suppressants, vehicular controls, and equipment modifications.

[1] Maurer, D., J.A. Koziel, J.D. Harmon, S.J. Hoff, A.M. Rieck-Hinz, D.S. Andersen. 2016. *Summary of performance data for technologies to control gaseous, odor, and particulate emissions from livestock operations: Air management practices assessment tool (AMPAT).* Data in Brief, 2016, vol.7, 1413-1429. DOI = 10.1016/j.dib.2016.03.070.

Appendix A.2: List of State Programs and Regulations for AFO Air Emissions

This table lists the agencies in each state that are responsible for regulating emissions of air pollutants. In addition, we have identified state/local agencies that have programs or rules specifically targeted at agricultural air emissions.

	Relevant Agency	Specific Ag Program?		Relevant Agency	Specific Ag Program?
Alabama	ADEM	No	Montana	DEQ	No
Alaska	ADEC	No	Nebraska	NDEQ	No
Arizona	ADEQ	PM_{10}[a]	Nevada	NDEP	No
Arkansas	ADEQ	No	New Hampshire	NHDES	No
California[b]	CalEPA	Yes[c]	New Jersey	NJDEP	No
Colorado	CDPHE	Odor/NH_3[d]	New Mexico	NMED	No
Connecticut	DEEP	No	New York	DEC	No
Delaware	DNREC	No	North Carolina	DEQ	Odor rule[k]
Florida	DEP	No	North Dakota	NDDoH	No
Georgia	DNR	No	Ohio	Ohio EPA	Air emission[l]
Hawaii	DOH	No	Oklahoma	ODAFF	No
Idaho	DEQ, ISDA	NH_3[e] PBR	Oregon	DEQ, ODA	Dairy air[m]
Illinois	IEPA	No	Pennsylvania	DEP	DA: Odor[n]
Indiana	IDEM	No	Rhode Island	DEM	No
Iowa	DNR	Yes[f]	South Carolina	DHEC	No
Kansas	KDHE	No	South Dakota	DENR	No
Kentucky	DEP	No	Tennessee	TDEC, TDA	No
Louisiana	LDEQ	No	Texas	TCEQ	Air PBR[o]
Maine	DEP	No	Utah	DEQ	No
Maryland	MDE, MDA	NH_3[g] (Bay area)	Vermont	ANR, VAAFM	No
Massachusetts	EEA, MassDEP	No	Virginia	DEQ	No
Michigan	MDA, DEQ	No	Washington[p]	ECY	No
Minnesota	MPCA	PM, H_2S[h]	West Virginia	DEP	No

Mississippi	MDEQ	PM[i]	Wisconsin	DNR	Odor & air[q]
Missouri	DNR	Odor rule[j]	Wyoming	DEQ	No

a) **Arizona-ADEQ**: Guide to Agricultural PM_{10} Best Management Practices: https://www.azdeq.gov/environ/air/plan/download/webguide.pdf

b) **California Air Resources Board Air Pollution Control Districts:**
Imperial County: Rule 420 (Livestock Feed Yards)
San Joaquin Valley:
Rule 4550 (Conservation Management Practices)
Rule 4565 (Biosolids, Animal Manure, and Poultry Litter Operations)
Rule 4570 (Confined Animal Facilities)
Dairy & Feedlot CMP handbook
http://www.valleyair.org/farmpermits/updates/cmp_handbook_for_dairies_and_feedlots.pdf
Poultry CMP handbook
http://www.valleyair.org/farmpermits/updates/cmp_poultry_handbook.pdf
South Coast: Rule 1133.2 (Emission Reductions from Co-Composting Operations)

c) **CalEPA**: Confined animal facilities http://www.arb.ca.gov/ag/caf/caf.htm

d) **Colorado-CDPHE**: AFOs/CAFOs air quality control regulation (odor) https://www.colorado.gov/pacific/sites/default/files/Regulation-Num-2-Part-B-Odor-Emissions.pdf
Ammonia reduction: https://www.colorado.gov/pacific/cdphe/ammonia-reduction

e) **Idaho-DEQ**: Permit by rule for dairies (dairy rule for the control of ammonia emissions) https://www.deq.idaho.gov/permitting/air-quality-permitting/permit-by-rule/dairies/ & List of dairy NH_3 BMPs https://www.deq.idaho.gov/media/635604-dairy_bmps.pdf

f) **Iowa-DNR**: AFO-AQ: http://www.iowadnr.gov/Environment/AirQuality/AnimalFeedingOperations.aspx

g) **Maryland-MDE**: NH_3 in Chesapeake Bay from Poultry Houses http://dnr.maryland.gov/ccs/Publication/articles_avihome.pdf & NH_3 mitigation http://dnr.maryland.gov/ccs/Documents/IT_FactSheet.pdf

h) **Minnesota-MPCA**: Odor program http://www.pca.state.mn.us/index.php/air/air-monitoring-and-reporting/air-emissions-modeling-and-monitoring/mpca-odor-policy.html & Feedlot air quality http://www.pca.state.mn.us/index.php/view-document.html?gid=3628

i) **Mississippi – MDEQ**: CAFO Multimedia General Permit (air emissions associated with mortality incineration equipment)
https://www.deq.state.ms.us/MDEQ.nsf/page/epd_AgriculturalBranchEPD?OpenDocument

j) **Missouri-DNR:** Odor rule (10 CSR 10-6.65)
http://www.sos.mo.gov/cmsimages/adrules/csr/current/10csr/10c10-6b.pdf

k) **North Carolina-DEQ**: Odor rule http://daq.state.nc.us/rules/rules/Sec1800.shtml

l) **Ohio-Ohio EPA**: NH_3-H_2S emission rates for poultry operations http://epa.ohio.gov/portals/27/serc/CAFOpoultryemissions.pdf & NH_3-H_2S emission worksheet for dairy cow operations http://epa.ohio.gov/portals/27/serc/CAFODairyEmissionsWorksheet.pdf

m) **Oregon-DEQ:** Dairy air http://library.state.or.us/repository/2012/201204101013082/

n) **Pennsylvania-DEP**: Odor management program http://www.agriculture.pa.gov/Protect/StateConservationCommission/OdorManagementProgram/Pages/default.aspx#.VgGE_U3snct

o) **Texas-TCEQ**: Air permit by rule (PBR) for AFOs and CAFOs https://www.tceq.texas.gov/permitting/air/permitbyrule/subchapter-f/afo.html & http://texreg.sos.state.tx.us/public/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=30&pt=1&ch=106&rl=4 & http://texreg.sos.state.tx.us/public/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=30&pt=1&ch=106&rl=161 & http://texreg.sos.state.tx.us/public/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=30&pt=1&ch=321&rl=43

p) **Washington-Ecology Clean Air Agencies**: http://www.ecy.wa.gov/programs/air/local.html

Yakima: Air Quality Management Policy & BMPs for Dairy Operations & https://www.yakimacleanair.org/img/pdf/109.pdf

Fugitive Dust Control Guideline & BMPs for Confined Heifer Replacement & https://www.yakimacleanair.org/img/pdf/110.pdf

Fugitive Dust Control Guideline & BMPs for Beef Cattle Feeding Operations https://www.yakimacleanair.org/img/pdf/111.pdf

q) **Wisconsin-DNR**: Odor and air emissions:

http://dnr.wi.gov/topic/AgBusiness/nonmanureAgchemicals.html & Beneficial management practices (BMPs) for mitigating hazardous air emissions from animal waste in Wisconsin: http://dnr.wi.gov/topic/AirQuality/documents/bmp/FinalReport101213.pdf

Appendix A.3: List of AFO Air Quality Programs & Land-Grant Universities

Organization	About	Web Location
USDA-NRCS	National Conservation Standards	http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849
eXtension	Air quality in animal agri., Farm energy anaerobic digestion and biogas	http://www.extension.org/pages/15538/air-quality-in-animal-agriculture#.VgiB2iBVikp, http://articles.extension.org/pages/31732/farm-energy-anaerobic-digestion-and-biogas
U.S. Composting Council	Composting	http://compostingcouncil.org/resources/
University of Arkansas	Air quality	http://www.uaex.edu/environment-nature/air-quality/default.aspx
UC Davis	Agri. air quality	http://animalscience.ucdavis.edu/faculty/Mitloehner/
Colorado State	NH_3 BMPs for livestock	http://extension.colostate.edu/topic-areas/agriculture/best-management-practices-for-reducing-ammonia-emissions-1-631/
University of Delaware	Poultry house emissions	http://sites.udel.edu/vebscrubber/
University of Florida	GHG Odor	http://dairy.ifas.ufl.edu/other/files/Wilkie-ReducingFloridaGHG-p33-38-2008.pdf & http://dairy.ifas.ufl.edu/other/files/Wilkie-Research-brief.pdf
University of Georgia	Poultry NH_3 GHGs	https://www.poultryventilation.com/research/ammonia-concentrations-poultry-house-fencelines & http://www.caes.uga.edu/content/dam/caes-website/departments/poultry-science/documents/greenhouse-gas-emissions-from-livestock-poultry.pdf
University of Idaho	Dairy NH_3 BMPs	http://agwastemanagement.usu.edu/files/uploads/Dairy_Ammonica_Control_Practices.pdf
Purdue	NAEMS Dairy air quality	https://engineering.purdue.edu/~odor/NAEMS/index.htm https://www.extension.purdue.edu/dairy/waste/wastepub_air.htm
Iowa State	AMPAT	http://www.agronext.iastate.edu/ampat/
Kansas State	Air quality	http://www.bae.ksu.edu/~zifeiliu/Research
University of Mass. Amherst	Dairy air quality	http://ag.umass.edu/fact-sheets/air-quality-issues-for-dairy-operations
Michigan State	Air quality	http://animalagteam.msu.edu/animalagteam/air_quality
University of Minnesota	Manure management & Air quality	www.extension.umn.edu/agriculture/manure-management-and-air-quality/air-quality/

University of Missouri	Air quality	http://extension.missouri.edu/main/DisplayCategory.aspx?C=263 & http://web.missouri.edu/~limt/ & http://web.missouri.edu/~limt/MitigationTests.shtml
University of Nebraska	Air quality	http://water.unl.edu/manure/air-quality https://articles.extension.org/pages/60702/animal-agriculture-and-climate-change
Cornell Waste Management Institute	Composting	http://cwmi.css.cornell.edu/
North Carolina State	Air quality	http://www.bae.ncsu.edu/topic/airquality/ http://www.bae.ncsu.edu/topic/animal-waste-mgmt/odor.htm
North Dakota	Odor & PM	https://www.ag.ndsu.edu/manure/documents/nm1391.pdf
Ohio State	Agri. air quality	https://airquality.osu.edu/extension
Oklahoma State	Agri. air quality	http://buser.okstate.edu/air-quality/
Penn State	Air quality, Odors, and Vegetative buffers	Air Quality: http://agsci.psu.edu/aec/webinars-presentations/manure-du-jour/air-quality, Odors: http://abe.psu.edu/research/natural-resource-protection/odors, Vegetative buffers: http://extension.psu.edu/animals/poultry/topics/vegetative-buffers
Clemson	CAMM	http://www.clemson.edu/extension/livestock/camm/
University of Tennessee	Livestock extension	https://extension.tennessee.edu/RTBurns/Pages/default.aspx
Texas A&M	TAMMI CAAQS	http://tammi.tamu.edu/ http://caaqes.tamu.edu/
Utah State	Air quality	http://agwastemanagement.usu.edu/htm/air-quality
Virginia Tech	NH_3	https://pubs.ext.vt.edu/442/442-110/442-110.html & https://pubs.ext.vt.edu/442/442-110/442-110_pdf.pdf
Washington State	Odor & air quality	Western region odor & Air quality https://labs.wsu.edu/ndegwa/woaq/ & Livestock nutrient management http://puyallup.wsu.edu/lnm/ & Livestock feed management https://puyallup.wsu.edu/lnm/publications
University of Wisconsin-Madison	CAFO emissions	http://fyi.uwex.edu/?s=CAFO&x=0&y=0 http://fyi.uwex.edu/midwestmanure/files/2013/03/Odor-Control-Technologies-Stowell.pdf