DESCRIPTIONS OF BEST MANAGEMENT PRACTICES

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The purpose of this document is to present brief descriptions of each best management practice (BMP). The descriptions are presented in a system-specific manner which includes Nutrition, Feed Management, Housing (Freestall Barns), Housing (Drylot Pens), Grazing, Manure Management, and Land Application (Fertilizer and Manure). Not all areas or BMPs presented here may apply to your farm. Pollutants reduced by each BMP are presented in parenthesis. These descriptions are not intended to provide detailed information as to how the BMPs should be implemented. It is expected that exact implementation will vary from farm to farm. When applicable, tradeoffs and/or limitations for each BMP are listed.

***Definitions**: NH_3 – ammonia; N_2O – nitrous oxide; H_2S – hydrogen sulfide; CH_4 – methane; VOC – volatile organic compounds; PM – particulate matter.*

I. Nutrition

1. Reduce the Amount of Dietary Protein (N) in the Ration to Match, rather Than Exceed, the Animal's Needs (NH_3, N_2O, Odor)

The most effective and practical way of reducing ammonia (NH_3) emissions is through proper feeding of dietary nitrogen (N). In the diet, the primary source of N is protein. Excess dietary nitrogen is excreted in the urine as urea, which reacts with the fecal enzyme urease and volatilizes as NH_3. Most, if not all, research agrees that proper feeding of dietary protein N will result in an NH_3 reduction. Studies show that the maximum nitrogen retention efficiency in cows is only 50% (1), with the typical efficiency at 38%, so small changes can have a big effect. For example, reducing the protein in the diet from 19 to 14% has shown to reduce urinary urea excretion and subsequent NH_3 emissions by 33% (2) with no reduction in milk production.

Proper levels of protein diet has several other advantages in addition to reducing NH_3 emissions:1) it reduces operating costs since protein is the most expensive component of the feeds, 2)it will result in healthier animals, and 3) improves nitrogen to phosphorus (N:P) ratio for crops when manure is applied to crop land.

Tradeoffs/Limitations: None

2. Increase the Level of Starch in the Diet (CH_4)

Increasing the level of starch or rapidly fermentable carbohydrates in the diet impacts the rumen pH of the rumen and microbial population, both of which regulate methane production (3, 4). Since methane emission is the byproduct of incomplete digestion, higher quality diets will allow animals to better digest their feed, be more efficient, and decrease methane production potential.

Tradeoffs/Limitations: None

3. Properly Manage and Minimize Overfeeding Sulfur in the Diet (H_2S, Odor)

A reduction in sulfur intake to maintenance levels will decrease excretion of sulfur compounds and thus, the emission of odorous gases such as hydrogen sulfide (H_2S).

Tradeoffs/Limitations: None

4. Practice Phase-Feeding (NH_3)

Phase-feeding is the separation of cattle (i.e., high milk cows, low milk cows, dry cows, heifers, and calves) into groups based on the dietary needs of each group. The goal is to feed only the necessary nutrient levels, such as protein, for growth and/or milk production to each group. Phase-feeding is very effective in reducing NH_3 emissions because it matches the protein needs of each group more precisely without over or under feeding a nutrient to the whole herd. Phase feeding can also save money by practicing precision feeding for each group.

Tradeoffs/Limitations: None

5. Increase Animal Efficiency (NH_3, CH_4, H_2S, Odor)

This BMP is accomplished through good genetic selection of cows, feed additives (when appropriate), proper handling or animals, and housing changes. Compared to dietary BMPs, this practice results in relatively small emission reductions and may take a long time to achieve results as in the case of genetic selection.

Tradeoffs/Limitations: None

II. Feed Management

1. Properly Manage (i.e. cover, confine, and reduce leaks in silage bags) Ensiled Feedstuffs (VOC, Odor)

Due to the release of organic alcohols during fermentation, silage has been found to be a significant source of VOC and odor emissions when exposed to the air. Therefore, properly covering, confining, and reducing leaks in silage storage can result in emission reductions. The primary reduction pathway is managing covered silage piles to minimize the surface area of the face and the duration of exposing the face where feed is accessed. After accessing feed from a covered silage pile, pull a cover over the face to reduce exposure, or covered exposed piles for maximum VOC reduction.

Tradeoffs/Limitations: None

2. Store Feed in a Weatherproof Storage Structure during the Wet Season (VOC, Odor)

Since moisture is primary to fermentation and fermentation primary to VOC and odor emission, it is important to minimize the potential for feed becoming wet. Weatherproof storage will prevent feed from becoming wet and diminish potential for spoilage and fermentation. Store feed in a covered bunker with proper drainage, or cover exposed feed piles during the wet season. Tradeoffs/Limitations: None

3. Remove Spilled and Unused Feed from Feeding Area on a Regular Basis (VOC, Odor, PM)

Spilled and unused feed is a source of VOC, odor, and PM emissions. Removing such feed from the storage and loading area at least every two weeks, or more frequently during wet periods, will diminish the potential for emissions.

Tradeoffs/Limitations: None

4. Do Not Mix Feed During Windy Times (PM)

Mixing, grinding and chopping of feed during windy times can be a significant source of PM emissions, as well as a waste of feed. Avoiding such activity or performing in a sheltered area, during wind events will diminish the potential for PM emissions and transport from feed processing activities.

Tradeoffs/Limitations: None

III. Housing – Freestall Barns

*1. Ensure Proper Ventilation (NH_3, Odor, PM)*Temperature is a very important factor in the rate of NH_3 volatilization. As the ambient temperature increases, NH_3 emission increases. Studies show that an increase in ambient housing temperature from 50 to 75º F results in a 46% increase in NH_3 emissions (5). Thus, reducing the temperature inside of freestall barns with proper ventilation or cooling of the barns reduces the NH_3 volatilization potential, and reduces animal heat stress, which can lower milk production. Odor and PM emissions are likewise reduced by this BMP.

Tradeoffs/Limitations: None

2. Scrub Exit Air from Enclosed (Forced Ventilation) Buildings (NH_3, H_2S, OdorCH_4*)*

Forced ventilation buildings are not common in dairy production, but enclosed manure storage systems can be. Using bio-filters to scrub the exit air from barns and manure storage facilities can significantly reduce NH_3 emissions as well as H_2S, odor, and CH4 emissions. Bio-filters are only practical for enclosed barns and vary in style, function, and effectiveness. A technical assistant is necessary to design and implement this BMP effectively.

Tradeoffs/Limitations: None

3. Use Nonabsorbent or Nonreactive Bedding (NH_3, H_2S, Odor)

The use of nonabsorbent bedding materials may help reduce NH3 and odor when managed well. Different types of bedding materials are used in dairy barns, but the most common are sand, wood shavings, chopped straw, and recycled manure. Among these materials, studies have shown that sand has the lowest NH_3 emissions when managed correctly (scraped daily, restocked weekly, and completely cleaned out annually). This is due to the fact that sand is non-absorbent and allows urine to infiltrate through the sand, reducing the contact time with ambient air. Composted manure solids do not allow urine to percolate through the substrate, but have low and consistent ammonia emissions when "fluffed" with a deep rake every few days and restocked regularly to promote continual microbial processing in the bedding material.

In general, proper management of *any* type of bedding, including frequent restocking, daily removal of solid manures, and annual bed change, will significantly reduce the potential of NH3 volatilization from all bedding types. H_2S and odor emissions are similarly reduced by this BMP. Keeping cows from defecating on bedding material by sizing freestalls correctly will also have a significant reduction in emission potential.

Tradeoffs/Limitations: None

*5. Eliminate Urinating on Bedding Material (NH_3, Odor)*Reducing the potential of fecal and urine deposition on freestall bedding is accomplished by designing the stall such that the urine and feces is expelled beyond the bedded area. This can be accomplished with stall sizing modification by adding top bars or limiting bed size, and/or by matching stall size to animal size. For example, housing heifers in cow barns may facilitate an uneven match up of animal and bed size, allowing smaller animals the ability to defecate on bedding material.

The daily practice of scraping solid manure from the bedding surface helps reduce odor, but may have limited effect on ammonia volatilization potential.

Tradeoffs/Limitations: None

6. Treat Recycled Lagoon Water Used for Flushing (NH_3, Odor)

For barns that practice flushing as a means of manure removal from alleyways, treatment in the form of solids removal or use of additives that discourage NH_3 hydrolysis (i.e., pH reducers, urease inhibitors, or biological additives) can help reduce ammonia and odor emissions. Using the cleanest or most dilute water from a multi-stage lagoon system will decrease the reintroduction of odorant materials.

Tradeoffs/Limitations: Infrastructure and additive cost.

7. Remove Manure from Barns Frequently (NH_3, VOC, Odor, CH_4)

Ammonia volatilization is a function of the mixing time of manure on the stall floor right after it is deposited. The production of ammonia begins immediately and peaks only a few hours after mixing. Odor and VOC production also occurs immediately after manure deposition and continues until removal. Thus, an effective way of reducing emissions from barns is by removing the manure at frequent intervals.

Typically, manure removal is performed with a scrape or vacuum system at milking times when cattle are out of the barn, but can occur more frequently with the use of a flush system or automatic scrapers. Studies have shown that a flush system is more effective at reducing ammonia volatilization over a scrape system, and that more frequent manure removal, every 2-4 hours, reduces odor and ammonia (6). However, the most effective system is one that removes all manure from the alleyway without leaving piles on the edges or reducing it to a thin film on the surface. These inefficiencies can actually lead to an increase in ammonia volatilization via increased mixing and surface exposure. This BMP is also effective in reducing, VOC, Odor, and CH_4 emissions.

Tradeoffs/Limitations: None

8. Modify Alleyway Floors (NH_3, VOC, Odor)

In freestalls, most of the manure is deposited in the alleyways where the mixing rate is highest. Minor changes or modifications to the floor surface that reduce the contact time of urine and feces could make a large difference in NH_3 emission. Modification to a 3% sloped floor, over a level (0%) one, encourages transport of urine away from solid manure and could reduce NH_3 emission by 21% (7, 8). A double slope with a gutter in the middle to trap the urine could reduce emission by 50% compared to solid floors (7). Grooved concrete floors that allow urine to collect in channels will help in reduction of NH_3, since the main objective is to separate the urine from the feces and reduce contact time. In addition, surface texture or permeable matting will aid in traction and increased hoof health. This BMP is also effective in reducing, VOC, Odor, and CH4 emissions.

Tradeoffs/Limitations: Modification with this BMP may not be possible for existing barns. New construction should follow these guidelines.

IV. Housing – Drylot Pens

1. Provide Shade for Cattle (NH_3, PM)

Ammonia volatilization is dependent on the mixing of urea and the urease enzyme from urine and feces, respectively. By spreading out the distribution of urine and feces over the pen surface, the mixing potential is reduced. The installation of a shade structure in the center of the pen will aid in distribution of defecation events because the animals will follow the shade during the day, dispersing manure and reducing the opportunity for mixing. This also helps to control course PM by more uniform surface wetting and compaction, and aids in reduction of animal heat stress

Tradeoffs/Limitations: None

2. Locate Feed and Water Opposite in Pens (NH_3, PM)

Placing the water trough and the feed bunk opposite each other in the pen, or rotating the locations (when applicable), helps to spread the feces and urine over a larger area of the pen surface, reducing the opportunity for mixing. This also helps to control course PM by more uniform surface wetting and compaction.

Tradeoffs/Limitations: This BMP may not be possible for all pen designs.

3. Remove and Spread (Harrow) Manure Frequently (NH_3, PM)

Ammonia emissions from open drylot pens are due to infrequent manure removal. There are two types of in-pen manure management, spreading/harrowing and complete manure removal. Depending on stocking density, manure in drylot pens should be completely cleaned out every one to three months. This reduces the amount of substrate available for ammonia volatilization and minimizes PM (dust) production from animal hoof action on the loose manure pack. Areas where manure deposition is highest (i.e., sleeping areas, feed bunks), can be cleaned more often (monthly, weekly). Installation of concrete alleyways adjacent to feedbunks aids in daily collection of manure and further reduces ammonia volatilization potential.

The daily harrowing of pens should be practiced to spread out the manure pack, but should only be done during periods of the day when PM production will not be an issue, such as the early morning. Tradeoffs/Limitations: None

4. Use Straw Bedding in Drylot Pens (NH_3, PM, Odor)

The application of a layer of straw bedding to drylot pens is commonly used as a wintertime management tool to reduce pen wetness and provide animals with a dry layer. However, the addition of straw bedding also aids in the separation of urine and feces to reduce ammonia volatilization, and will aid reducing particle (PM) production from the pen surface. This practice can be utilized year-round for increased ammonia, PM, and odor reduction.

Tradeoffs/Limitations: None

5. Incorporate Wood Chips in Surface Layer (NH_3, PM, Odor)

Incorporating woodchips (0.5 inch diameter average) into the pen surface layer will manage moisture content and encourage aeration of the manure pack. The increase in aeration reduces ammonia, odor, and PM. Woodchips should be placed approximately four inches thick in areas where animals tend to congregate and/or deposit manure (i.e., sleeping areas, under shade, near feedbunk). Areas should be harrowed daily to encourage aeration and reduce compaction of the surface layer and restocked with woodchips as needed.

If manure is harvested from pens for composting, the addition of woodchips to the pen increases carbon content of the compost and eliminates the extra step of adding and mixing the woodchips later in the process.

Tradeoffs/Limitations: None

6. Application of Surface Treatments that Bind or Inhibit NH_3 (NH_3)

The pH of the soil surface greatly affects the rate of ammonia volatilization. If the soil is acidic, a pH below 6, ammonia volatilization will be low. At a higher pH, above 8, ammonia will volatilize rapidly from the soil surface. Additionally, the urease enzyme is very active at a pH between 6.8 and 7.6, amplifying the volatilization process. Thus, the pH of the soil or surface where manure and urine are deposited can greatly affect the NH_3 emission rate. Surface treatment of aluminum sulfate (alum) to reduce pH has been shown in a laboratory setting to reduce the cumulative NH_3 emissions by 98% over a 21 day period (9). Calcium chloride, a microbial inhibitor, has been shown to reduced emissions by up to 77% under laboratory conditions (9). While these treatments are very successful under laboratory settings, application in "real-world" conditions yields highly variable and typically poor results. This is due in part to surface evaporation, animal hoof action, and weather conditions. The addition of an additive to the surface of a pen is also very expensive and labor intensive. If surface acidifiers are to be used, effectiveness will first need to be established, then frequency of application can be determined. Under average dry conditions, acidifiers typically need to be applied weekly for maximum effectiveness.

Tradeoffs/Limitations: Can be very expensive to install and maintain effectiveness of surface treatments.

7. Urease Inhibitors (NH_3, N_2O)

Another method of reducing NH_3 from drylot pens is enzymatic treatment with urease inhibitors, which inhibit the urease enzyme in feces from reacting with urea and volatilizing as ammonia. Several inhibitors are available such as N-(n0butyl) thiophosphoric triamide (NBPT), which is the most effective in preventing the hydrolysis of urea. Urease inhibitors can either be fed to cattle in feed rations or surface applied to the pen surface. Similar to surface acidifiers, urease inhibitor effectiveness is highly variable and can be very costly to achieve significant reductions. This BMP is also relatively effective in reducing N_2O emissions by limiting nitrification.

Tradeoffs/Limitations: Can be very expensive to install and maintain effectiveness of surface treatments.

8. Avoid Over-application of Water to Pen Surface after Sustained Dry Periods (NH_3, N_2O)

Over-application of water on a dry pen surface activates the hydrolysis and nitrification process, leading to ammonia volatilization and nitrous oxide "bursts", respectively. Water should only be applied to pen surfaces as a dust (PM) mitigation tool and be applied such that it forms a cohesive moist layer on the surface but does not penetrate too deeply into the surface.

Tradeoffs/Limitations: None

9. Avoid Standing Water (VOC, Odor, CH_4, H_2S)

Standing water encourages anaerobic conditions, which can lead to odor, CH_4, H_2S, and VOC emissions and should be avoided. This can be accomplished by grading pens to a minimum 3% slope to channel water away from the pen and into a collection area. Contained runoff can then be treated or land applied. Daily harrowing of pens, filling of holes, and center piling will aid in reducing pen conditions that could encourage surface ponding.

Tradeoffs/Limitations: None

10. Maintain the Surface Moisture Content at 26% (Odor, PM)

The moisture content of the pen surface is directly linked to odor and dust (PM) production, which are inversely related. Increasing the moisture content of the pen surface binds surface manure and soil particles to limit the production of dust, but too much moisture encourages the production of odorous compounds. Inversely, a low moisture level will decrease the production of volatile fatty acids and other odorous compounds, but will greatly increase the production of dust. Therefore, a surface moisture level of approximately 28% has been suggested to balance odor and dust (10). This can be accomplished with strategic water application, increased stocking density to increase manure application, surface bonding additives, installation of straw bedding, addition of wood chips to the surface layer, construction of a shade structure, or modified pen layout and design. This practice requires routine monitoring of surface moisture content to identify the optimal level of moisture to limit both odor and PM in a specific pen.. Tradeoffs/Limitations: Surface conditions must be monitored on a daily basis.

11. Knock Down and Remove Fence Line Manure (VOC, Odor)

Deep buildup of manure along fence lines provides opportunity for anaerobic decomposition and fly proliferation. Manure should be knocked down and either spread or removed when buildup is greater than 12 inches deep.

Tradeoffs/Limitations: None

V. Grazing Management

Air emissions reductions are identified in parentheses for each practice used in grazing management below:

1. Stock Appropriate Number of Animals (NH_3, N_2O)

Overstocking of animals increases ammonia volatilization from pastures by increasing the concentration of manure on the field and reducing the amount of plant cover and N uptake. Stocking animals at appropriate rates and intervals for each field will reduce over application of manure and maintain pastures. Tradeoffs/Limitations: None

2. Use Rotational Grazing (NH_3, N_2O)

Practicing rotational grazing will help maintain pasture forage growth and health, which will maximize plant uptake of applied manure and reduce the potential of NH_3 or N_2O emission. Pastures should be evaluated on a daily basis for plant height and quality, and animals should be removed when plants are less than three inches in height or stem density is less than 85%.

Tradeoffs/Limitations: None

3. Move Water and Feeding Areas Frequently (NH_3, N_2O)

Since the volatilization of NH_3 is dependent on the mixing of urine (urea) and feces (urease), dispersing these events evenly over a pasture surface can help reduce NH_3 volatilization. Animals on pasture tend to concentrate elimination behaviors around the water trough, feeding, and/or sleeping areas. Studies show that the number of elimination events that occur in a location is highly correlated with the time spent at the location (18). Therefore, the deposition of manure can be affected by the management and layout of the pasture environment. In a pasture situation, this can be accomplished by moving the water trough and feed stations periodically to a new location to disperse cattle activity and manure deposition. This will also prevent plant suffocation and trampling in heavily populated areas of the pasture.

Tradeoffs/Limitations: None

4. Irrigate Immediately after Grazing (NH_3)

Irrigating pastures following grazing will help incorporate manure into the soil and reduce ammonia volatilization potential. Over irrigation can increase NH_3 volatilization and N_2O emission.

Tradeoffs/Limitations: None

5. Manage Pasture Plants to Increase Yield and Nitrogen Uptake (NH_3, N_2O)

Manage pasture forage with proper stocking rates, rotation grazing practices, exclusion, irrigation, and fertilizer application as needed. Practices that increase the health and vigor of the forage will increase nitrogen uptake and reduce the reservoir available for NH_3 and N_2O emission.

Tradeoffs/Limitations: None

VI. Manure Management

Air emissions reductions are identified in parentheses for each practice used in manure management below:

1. Manure Solids Separation (NH_3, VOC, Odor, H_2S, CH_4)

Solid separation is the removal of the solid portion of the manure waste stream from the liquid portion. The liquid portion is transferred to the storage vessel (i.e., lagoon, tank) and the solid portion is stockpiled, composted, or land applied. The types of solid separation vary, and include screens, earthen pits, leaky dams, presses, and others. Approximately 25% of the total manure N is removed with the solids (1); the remaining portion stays with the liquid portion of the manure. This helps in reduction of ammonia volatilization potential from the storage vessel. Maximizing the efficiency of solids separation (greater than 50% removal), will decrease the volume of solids in the liquid storage, which reduces ammonia, odor, hydrogen sulfide, and methane formation.

Tradeoffs/Limitations: None

2. Cover or Allow Crust to Form on Lagoon Surface (NH_3, H_2S, VOC, Odor, CH_4)

The rate of volatilization from the surface of a lagoon is influenced by environmental factors such as ambient temperature, relative humidity, surface wind velocity, and precipitation. To control these factors, the addition of a cover to the lagoon can reduce uncontrollable variables and capture unwanted emissions. A cover can be a floating plastic cover, a synthetic or natural cover of peat, straw, or polystyrene, or a natural cover formed by the presence of dry matter in the lagoon. When working properly, any of these covers can reduce nitrogen losses by 80-90% (1), as well as control odor, hydrogen sulfide, and methane losses, but any cracks in the cover will greatly reduce this efficiency.

The establishment of a natural crust on the lagoon surface, typically formed by the movement and cohesion of solids to the lagoon surface, can reduce ammonia losses by up to 50% (11). The formation of a natural crust will occur when the lagoon has high solids content, the ambient air is dry, and there is little precipitation to break the crust.

Covers *must* be checked regularly and maintained to prevent leakage and loss of pollutants from the cover. Secondary treatment methods of captured gas via biofilters, flaring, scrubbing, or other method should be maintained and operated effectively to minimize losses.

Tradeoffs/Limitations: Cost and maintenance time of covers can be high.

3. Scrub Exhaust of Enclosed Waste Containers (CH_4, Odor, H2S)

Using bio-filters to scrub the exit air from manure storage facilities can significantly reduce NH_3, H_2S, odor, and CH_4 emissions. Bio-filters vary in style, function, and effectiveness. A technical assistant is necessary to design and implement this BMP effectively.

Tradeoffs/Limitations: This practice requires technical assistance to install and maintain.

4. Install and Properly Maintain a Methane Digester (CH_4)

The installation of a methane digester is only recommended for those facilities that can properly operate and maintain the digester. Various styles of digesters are available, but the overarching goal is to reduce methane emission from liquid manure by capture and conversion to energy or carbon dioxide. Hydrogen sulfide is also emitted and scrubbed from the exit air of the digester. While digesters may reduce methane, hydrogen sulfide, and odor from manure effluent, the digestion process increases the ammonia volatilization potential of the digestate once it leaves the digester and enters the storage lagoon. This BMP required technical assistance and has a high cost associated with installation and operation.

Tradeoffs/Limitations: Increases ammonia volatilization from effluent. High cost of installation. Requires technical assistance to install and operate properly.

5. Reduce the pH of Lagoons and Manure Piles (NH_3, CH_4)

If the pH of liquid manure stored in a lagoon or tank is maintained above 8 (basic), ammonia volatilization increases and losses may be up to 70% of the total nitrogen entering the lagoon (1). At a pH below 6 (acidic), ammonia is bound in solution and little ammonia volatilization will occur. Methane emission is also reduced at a pH below 6.5. Achieving a low lagoon pH (optimal is 4.5 for maximum reduction) requires the addition of acidifying compounds such as alum, citric acid, or nitric acid to the lagoon. Positive results have been found in reducing ammonia emissions from small-scale laboratory studies, but large scale application is limited due to cost and feasibility issues. Due to the natural buffering capacity of manure, large amounts of acidifiers are required, as is frequent monitoring of pH and addition of acidifying compounds. In addition, low pH reduces the efficacy of anaerobic lagoons and increases hydrogen sulfide and odor production.

A reduction in the pH of manure piles below 6 is achieved in a similar fashion as lagoons by adding an acidifier to the pile and monitoring the pH over time.

Tradeoffs/Limitations: Decrease ammonia and methane, but increases hydrogen sulfide and odor production. High cost, short effective period.

6. Encourage Purple Sulfur Bacterial Formation in Anaerobic Lagoons (H_2S, Odor)

Purple sulfur bacteria (PSB) are photosynthetic, anaerobic bacteria that grow in the presence of carbon dioxide (carbon source), nitrate (nitrogen source), and hydrogen sulfide (13). Purple sulfur bacteria oxidize the hydrogen sulfide in the lagoon for photosynthesis and produce elemental sulfur or sulfate as a photosynthetic by-product (14), both of which are less odorous than hydrogen sulfide. Since PSB are photosynthetic, the use and/or optimization of a solid separator can aid in light penetration and the proliferation of PSB in a lagoon. The conditions conducive to natural PSB formation are an anaerobic lagoon with low solids content and a pH in the 7.0 to 8.5 range (15). Population of PBS in a lagoon is very difficult to induce and typically happens naturally. Therefore, maintenance of an existing population is the most effective H_2S reduction method for lagoons.

Tradeoffs/Limitations: PSB conditions decrease hydrogen sulfide and odor production, but may increase ammonia volatilization. Difficult to induce PSB formation.

7. Properly Manage Composted Solid Manure (H_2S, Odor, PM, CH_4)

The effectiveness of the composting process is highly depended on good management of pile characteristics including temperature, moisture, carbon to nitrogen ratio (C:N), and aeration. Low temperature, high moisture, low C:N, and low aeration will lead to anaerobic conditions inside the manure pile and increase odor, H2S, and CH_4. A shift from anaerobic to aerobic process can cause a nitrification/denitrification cycle that can increase N_2O losses. Low C:N (below 12:1), high temperature, and high aeration of the compost pile will increase NH_3 volatilization, which can be up to 90% total N loss under these conditions (12). Low moisture will increase PM emissions. A C:N above 12:1, and optimally around 30:1, will have reduced NH_3 emissions, while still supporting an active composting process.

Tradeoffs/Limitations: None

8. Properly Manage Stockpiled Manure (H_2S, Odor, PM)

Stockpiled manure can easily become anaerobic from compaction, too much moisture, or organic matter breakdown if not managed properly. Anaerobic piles will emit odor, H_2S, and CH_4. Stockpiles should be stored in a covered area to avoid over saturation with rainwater.

Tradeoffs/Limitations: None

VII. Land Application – Manure and/or Chemical Fertilizer

Air emissions reductions are identified in parentheses for each practice used in Land Application of Manure and/or Chemical Fertilizer:

1. Apply N Fertilizer Directly to or Below the Surface Rather Than on Top of No-Till Residue (NH_3)

The practice of no-till crop harvesting is beneficial in reducing soil erosion from wind (PM) and water transport, and increasing or maintaining soil tilth. The stubble left behind creates a surface cover that helps protect against soil loss. When applying fertilizer the following year to new crops, the fertilizer should be applied under the crop residue, not on top. Appling fertilizer on top of the residue increases exposure to ambient conditions and ammonia volatilization losses.

Tradeoffs/Limitations: None

2. Inject or Incorporate Fertilizer into Soil within 24 Hours of Application (NH_3, Odor)

All fertilizer should be injected, incorporated, or applied as close to the ground surface as possible to limit ammonia volatilization losses and odor. Nitrogen fertilizer applied to crop land is available for volatilization losses if left on the soil or leaf surface, or sprayed through the air. Incorporation immediately after application (within 24 hours) via chisel, aeration, or irrigation (or precipitation event under 0.15 inches) is suggested for annual crop and forage fields and can reduce ammonia losses by up to 98% (1). Application of manure with a sleighfoot or other below leaf canopy surface applicator (i.e., drop hose irrigation) is recommended for forage fields to reduce NH_3 and odor. All of these methods work by moving fertilizer and/or manure into the soil profile away from the surface where volatilization and odor emission can occur. In addition to reducing emission losses, this method conserves more nitrogen in the soil increasing efficiency and reducing fertilizer costs.

Application of manure using a “big gun” or overhead sprinkler has the highest rate of ammonia loss out of all application methods. This is because the sprinkler exposes more manure surface area to the ambient air and a portion of the total nitrogen is volatilized as ammonia before the liquid manure even reaches the soil surface. Sprinkler application also has a higher rate of odor and transport when used during windy conditions. Broadcast application, which also exposes manure surface area to the ambient air, also has high ammonia losses (20 to 30% of total N) when not immediately incorporated. Therefore, practices like those mentioned above aimed at reducing the exposure time and increasing the size of the droplets should be encouraged.

For certain crops, controlled-release fertilizers or fertigation is an effective way to deliver chemical fertilizer to the plants at specific rates and times. This is an effective way to match crop needs and fertilization delivery to reduce the amount of N available for volatilization. These are more costly methods and require irrigation infrastructure to utilize.

Tradeoffs/Limitations: Deep injection of manure decreases NH_3 volatilization, but may increase N_2O emissions via denitrification.

Tradeoffs/Limitations: This practice is limited by the cost of application equipment and seasonal field conditions.

3. Apply Nutrients According to Agronomic Recommendations Based on Soil Test Results (NH_3, N_2O)

Application of chemical fertilizer and/or manure nutrients should always be made at agronomic rates to reduce excess application and losses. Agronomic application is the application of nutrients to meet crop 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 and subsequent NH_3 and N_2O emission can be avoided.

Tradeoffs/Limitations: None

4. Do Not Over-irrigate (NH_3, N_2O)

Irrigation increases soil water content and may increase N_2O emissions when over applied by promoting anaerobic conditions and increasing denitrification. When combined with nitrogen from fertilizer or manure application, the rate is increased. Irrigation to very dry soil can also increase N_2O and/or ammonia emission by microbial action. Irrigate at recommended levels and timing throughout the growing season. Tradeoffs/Limitations: None

5. Utilize Cover Crops(NH_3, N_2O, PM)

Cover crops reduce the amount of surface exposed and provide root structures to hold soil in place. The use of cover crops, instead of leaving fields bare/fallow, decreases wind erosion (PM) and losses of NH_3 and N_2O. Cover crops also reduce nitrate leaching during the wet season. Tradeoffs/Limitations: None

6. Apply During Cool Weather and on Still Rather than Windy Days (NH_3, Odor, PM)

Temperature, humidity, wind speed, and precipitation all influence the rate of NH_3, PM, and odor losses. Ammonia loss increases exponentially with rising temperatures, and increases with greater wind speeds. PM losses also increase with increasing temperatures which dry out the soil, and increased wind speed that moves soil and manure particles from the surface into the ambient air. Therefore, the application of manure during cool, still weather will decrease the amount of PM and NH_3 volatilized from the manure (16). Appling in the early morning or late evening will not only reduce NH_3 volatilization, but will also reduce the transport of PM and odor to surrounding neighbors. Light precipitation (less than 0.15 inches) following application can also decrease ammonia volatilization by binding ammonia in the aqueous phase and moving it into the soil profile.

Tradeoffs/Limitations: None

7. Use Windbreaks to Trap or Redirect Odor and PM (Odor, PM)

Relatively simple methods have been used to successfully reduce wind erosion including the use of windbreaks and smaller field widths, which decrease wind speed and surface area exposed. A windbreak, composed of trees or a physical barrier, will partially reduce wind speeds for a distance of roughly 30 times its height (17). A windbreak can also redirect PM and odor and provide a visual barrier. Use of a natural, vegetative barrier is recommended along farm perimeters and field edges bordering urban neighbors.

Tradeoffs/Limitations: None

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