APPENDIX C - DESCRIPTIONS OF BEST MANAGEMENT PRACTICES (BMPs) FOR AIR EMISSION REDUCTION ON DAIRY OPERATIONS

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The purpose of this document is to present brief descriptions of available best management practices (BMPs) for controlling air emissions from dairy operations. 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 components or BMPs presented here may apply to your farm. Pollutants impacted 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, limitations, or both are listed for each BMP.

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. Properly Manage Level of Dietary Protein (%CP) in Diet to Match, Rather Than Exceed, an Animal's Needs (NH_3, N_2O, Odor)

The most effective and practical way of reducing 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. In general, available research data has demonstrated that properly managed feeding of dietary protein N will result in an NH_3 reduction. Studies show that the maximum nitrogen retention efficiency in cows is approximately 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 emission by 33% (2), with no reduction in milk production. The recommended level of CP in the diet is approximately 16%, with considerations made for MUN and herd efficiency factors.

Added advantages of ensuring proper levels of protein in the diet, in addition to reducing NH_3 emissions, include:1) reduced operating costs considering protein is the most expensive component of the feeds, 2) healthier animals, and 3) improved nitrogen to phosphorus (N:P) ratio for crops when manure is applied to crop land.

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

Increasing the level of starch or rapidly fermentable carbohydrates in the diet impacts the rumen pH 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. The recommended level of starch in the diet is approximately 23-26%.

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). The recommended level of sulfur in the diet is 0.2-0.4% depending on stage of growth or lactation.

4. Practice Group and/or Stage of Lactation Feeding (NH_3)

Group feeding is the separation of cattle into groups (i.e., high milk cows, low milk cows, dry cows, heifers, and calves) 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 is synonymous with precision feeding and is both environmentally responsive and economical.

II. Feed Management

1. Properly Manage Ensiled Feedstuffs (VOC, Odor)

Due to the release of low molecular weight organic compounds during fermentation, silage has been found to be a significant source of volatile organic compounds (VOCs), which are responsible for odor in livestock operations. Properly covering, confining, and reducing the release of VOCs from silage storage can result in significant reduction of VOCs and odor emissions. Covered silage piles need to be properly managed during access to minimize VOCs emissions. The primary method of achieving this is to minimize the surface area of the face and the duration of face exposure where and when feed is accessed, respectively. The access face should be covered immediately after the required amount of silage has been obtained.

2. Store Feed in a Sheltered Storage Structure (VOC, Odor, PM)

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 via rainwater. 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. A feed bunker covered on three sides will also reduce PM emission by limiting wind exposure to and erosion of the pile.

3. Regularly Remove Spilled and Unused Feed from Feeding Area (VOC, Odor, and PM)

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

4. Manage or Minimize the Mixing of 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 activities, or performing them in a sheltered area during wind events, will diminish the potential for PM emission and subsequent transport from the feed processing area.

III. Milk Parlor

1. Ensure Proper Ventilation (NH_3, Odor, and 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 enclosed parlor and holding areas with proper ventilation and/or cooling reduces the NH_3 volatilization potential and reduces animal health effects, which can lower milk production. Odor and PM emissions are likewise reduced by this BMP by circulating air and removing stagnant odor and airborne PM from the enclosed areas.

2. Use Recycled Parlor (Clean) Water Used for Flushing/Cleaning Parlor (NH_3, Odor)

Using clean water, recycled parlor water, or most dilute water from a multi-stage lagoon system will decrease the reintroduction of odorant materials and reduce emissions. Recycling concentrated liquid manure through the holding area may increase both NH_3 and odor emissions and should be avoided.

3. Treat Recycled Water Used for Flushing/Cleaning Holding Area (NH_3, Odor)

For holding pens and parlors that practice flushing as a means of manure removal, treatment in the form of additives that discourage NH_3 hydrolysis (i.e., pH reducers, urease inhibitors, or biological additives) can help reduce ammonia and odor emissions.

4. Remove Manure from Holding Area Frequently (NH_3, VOC, Odor)

Ammonia volatilization is a function of the mixing time of manure on the stall floor right after it is deposited. The production of NH_3 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 parlors and holding areas is by removing manure at frequent intervals.

Typically, manure removal from parlors and holding areas is performed with a flush system. Studies have shown that a flush system is more effective at reducing NH_3 volatilization over a scrape system, and that more frequent manure removal, every 2-4 hours, reduces odor and NH_3 (6). Whether using a flush or scrape system, the most effective system is one that removes all manure from the alleyway without leaving piles on the edges or reducing it to a film on the surface. These inefficiencies can lead to an increase in NH_3 volatilization via increased mixing and surface exposure. This BMP is also effective in reducing, VOC, and odor emissions.

IV. Housing – Freestall Barns

1. Ensure Proper Ventilation of Freestall Barns (NH_3, Odor, and 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 and/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 by circulating air and removing stagnant odor and airborne PM from the barn.

2. Bedding Selection and Management (NH_3, H_2S, Odor)

The use of non-absorbent bedding materials may help reduce NH_3 and odor emissions when managed well. The most common bedding materials used in dairy barns include: sand, wood shavings, chopped straw, and recycled manure. Among these listed materials, studies have shown, for example, that sand-bedding results in the lowest NH_3 emissions when managed correctly (scraped daily, restocked weekly, and completely cleaned out annually). Sand is non-absorbent and allows urine to infiltrate through it, which reduces urine's contact time with ambient air. In contrast, composted manure-bedding does not allow urine to percolate through and, therefore, results in higher ammonia emissions than sand-bedding.

In general, however, 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 NH_3 volatilization from all bedding types. Hydrogen sulfide, which can form under anaerobic bedding conditions, and odor emissions are similarly reduced by this BMP. Most of all, keeping cows from defecating on the bedding material through proper sizing of freestalls has a significant reduction in emission potential by eliminating manure deposition on the beds in the first place.

3. 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 and reduce emissions as well. Recycling concentrated liquid manure through the barn may increase both NH_3 and odor emissions and should be avoided.

Tradeoffs/Limitations: Infrastructure and additive cost.

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

Ammonia volatilization is a function of the mixing time of manure on the stall floor right after it is deposited. In addition, the thin-spread manure provides more surface area, which exacerbates the respective emissions. The production of NH_3 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 (every 2 to 4 hours (6)).

5. Manure Removal Technology and Efficiency (NH_3, VOC, Odor)

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 NH_3 volatilization over a scrape system, and that more frequent manure removal, every 2 to 4 hours, reduces odor and NH_3 (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 NH_3 volatilization via increased mixing and surface exposure. This BMP is also effective in reducing, VOC, and odor emissions.

6. Alleyway Floor Texture and Type (NH_3, VOC, Odor)

In freestalls, most manure is excreted in 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 significant 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. Besides reducing emission potential, surface texture or permeable matting will aid in traction and increased hoof health. This BMP is also effective in reducing, VOC and odor emissions.

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

V. 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 as the animals 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.

2. Sitting of Water Trough Within Pen (NH_3, PM)

Placing the water-trough and feed bunk at opposite sides of the pen, or rotating the locations (when applicable), helps to spread feces and urine over a larger area of the pen surface, reducing the opportunity for mixing. This also helps to control coarse PM by more uniform surface wetting and compaction. Conversely, locating the water trough near the feed bunk concentrates surface wetting to a collected area (i.e., feed alley) and limits the movement of animals across a potentially dry pen, thus limiting course PM production.

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

3. Remove and/or 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: (i) spreading or harrowing, and (ii) complete manure removal. In general, manure in drylot pens should be completely cleaned out every one to three months. The reduction in the quantity of manure results in less ammonia volatilization and also minimizes PM (dust) production from animal hoof action on the loose manure pack. More frequent (monthly, weekly) removal of manure from areas where manure deposition is highest (i.e., sleeping areas, feed bunks) is desirable. Installation of concrete alleyways adjacent to feed-bunks 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 times of the day when PM production will not be an issue, such as the early morning.

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 in reduction of particulate (PM) production from the pen surface. This practice can be utilized year-round for increased ammonia, PM, and odor reductions.

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

Incorporating woodchips (1/2 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 shades, near feed-bunks). These areas should also be harrowed daily to encourage aeration and reduce compaction of the surface layer, and restocked with woodchips as needed.

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

6. Urease Inhibitors (NH_3, N_2O)

Reduction of NH_3 from drylot pens can be achieved through enzymatic treatment with urease inhibitors, which inhibit the urease enzyme in feces from reacting with urea and volatilizing as NH_3. 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.

7. Surface Moisture Content Management (NH_3, N_2O, VOC, Odor, CH_4, H_2S, Odor, PM)

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. The dust (PM) from a dry pen is inversely proportional to the pen surface moisture content. Increasing the pen-surface moisture content binds surface manure and soil particles to limit the production of dust. Too much moisture, however, encourages the production of odorous compounds. A compromise surface moisture level of approximately 28% has been suggested to balance odor and dust (10). Maintaining this moisture level can be accomplished through regular water application, surface bonding additives, use of straw or wood chips to the surface layer, construction of a shade structure, and pen layout and design. This practice requires routine monitoring of surface moisture content.

On the extreme end, standing water should also be avoided. Standing water promotes anaerobic conditions, which are responsible for odor, CH_4, H_2S, and VOC emissions. Standing water can be mitigated 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 reduce pen conditions that encourage surface-ponding.

8. Knockdown and Remove Fence Line Manure (NH_3, VOC, Odor)

Over time, manure builds up along fence lines. This build-up of manure along fence lines provides opportunity for anaerobic decomposition (odor) and fly proliferation. Manure should be knocked down and either spread or removed when build-up is greater than 12 inches deep.

VI. Grazing Management

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

Overstocking of cattle increases NH_3 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.

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 manure and reduce the potential of NH_3 or N_2O emission. Pastures should be evaluated on a regular 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%.

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, distribution of manure deposition can be effected via management and layout of the pasture environment. Moving water-troughs and feed-stations periodically to new locations will disperse cattle activity and thus manure deposition. This will also prevent plant suffocation and trampling in heavily populated areas of the pasture.

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, however, increase NH_3 volatilization and N_2O emission.

VII. Manure Management

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. Solid separation systems include: screens, rotary drums, centrifugal tanks, earthen pits, weeping walls, settling basins, screw-presses, and others. Approximately 25% of the total manure N is removed with the solids (1); the remaining N stays with the liquid portion of the manure. Solid separation reduces potential of NH_3, VOC, Odor, H_2S, CH_4 emissions from post-separation liquid storages.

2. Lagoon or Storage Covers (NH_3, H_2S, VOC, Odor, CH_4)

The emission rate from the surface of a lagoon is influenced by environmental factors such as ambient temperature, relative humidity, surface wind velocity, and precipitation. To control the effects of these factors, addition of a cover to the lagoon is necessary. Lagoon covers range from floating plastics, synthetic or natural peat, straw, polystyrene, and natural dry matter. When properly installed and managed well, any of these covers can reduce NH_3 losses by 80-90% (1), in addition to controlling odor, H_2S, and CH_4 losses. Any cracks in the cover should be taken care of immediately because they will compromise the efficiency of the cover.

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 a high solids-content, the ambient air is dry, and there is little precipitation to break the crust. While natural covers can reduce NH_3 and H_2S emissions, they need to be monitored for odor, which can emanate from the crust itself.

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

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 enclosed 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. Proper Operation and Maintenance of Anaerobic Digester (CH_4)

Anaerobic digestion (AD) converts manure into biogas (CH_4 and CO_2), which can subsequently be used for providing energy or heating on the dairy or for sale back into the electric grid. The two common types of digesters found on dairy operations are the plug flow type or the complete mixed digesters. The former is more appropriate for operations with scrape manure systems, while the latter is more suitable for dairies with manure flushing systems. The overarching goal of AD is to reduce methane emission from manure. Other gases produced during AD (H_2S, CO_2) can be scrubbed from the exhaust to provide natural, gas grade CH_4. Although AD reduces CH_4, H_2S, and odor emissions from AD effluent, the digestion process increases the ammonia volatilization potential from the AD effluent. This BMP requires technical assistance and has a high cost associated with installation and operation.

Tradeoffs/Limitations: Increases ammonia volatilization potential from effluent; high cost of installation; and requires technical assistance to install and operate properly.

5. Surface Aeration of Lagoons (NH3, H2S, VOCs)

The biodegradable organic materials in manure can be oxidized to stable end products by aerobic bacteria. These microorganisms require oxygen to affect this process. In general, if enough oxygen is provided, the end products of aeration are odor-free. The main problem is the cost of providing adequate oxygen for this process.

To reduce the cost of aeration, surface aeration is suggested as a method for mitigation of odor and other gases from anaerobic lagoons, which are released from incomplete manure decomposition. Surface aeration can complement anaerobic digestion by acting as a biological-blanket, aerobically degrading odorous compounds from the layer of anaerobic decomposition below. The aerobic bacteria in this blanket consume odorous volatile compounds and releases odor-free gases into the air. For example, this layer oxidizes ammoniacal nitrogen (NH_4^+, NH_3) into nitrate (NO_3^-), and oxidizes sulfur containing compounds such as H_2S into elemental sulfur (S) or sulfates (SO_4^{2-}). This process thus mitigates emissions of NH_3 and H_2S as well other volatile organic odorous compounds that may try to escape from the anaerobic zone below the aerobic blanket.

Tradeoffs/Limitations: High cost associated with running aerators; reduced effectiveness in lagoon with high solids content.

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

The pH of stored manure, liquid or solid, greatly affects the rate of H_2S and NH_3 volatilization. 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). Additionally, in solid manure, the urease enzyme is very active at a pH between 6.8 and 7.6, amplifying the volatilization process from manure piles. At a pH below 6 (acidic), NH_3 is bound in solution or tied-up and little NH_3 volatilization will occur from liquid or solid manure, respectively. Methane emission is also reduced at a pH below 6.5. On the other hand, low pH in the lagoon may result in elevated H_2S emissions and loss of efficiency of the anaerobic process, which may result in increased odor emissions.

Reduction of manure pH in lagoons and manure piles is achieved by addition of acidifying compounds such as alum or acids. However, due to the natural buffering capacity of manure, large amounts of acidifiers are required to reduce pH and frequent monitoring is necessary.

Tradeoffs/Limitations: Decrease ammonia and methane, but increases hydrogen sulfide and odor production; high cost; and only effective over short-periods.

7. Purple Sulfur Bacterial Formation in 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; difficulty in inducing PSB formation.

8. Properly Manage the Composting of Solid Manure (H_2S, Odor, PM, CH_4)

The effectiveness of the composting process is highly dependent on good management of pile characteristics including temperature, moisture, carbon to nitrogen ratio (C:N), and aeration. Low temperature, high moisture, and low aeration will lead to anaerobic conditions inside the manure pile and increase odor, H_2S, and CH_4 emissions. 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.

9. 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, or periodically turned to decrease compaction and achieve even moisture levels throughout the pile.

VIII. Land Application – Manure and/or Chemical Fertilizer

1. Apply N Fertilizer Below No-Till Residue (NH_3, PM)

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 NH_3 volatilization losses.

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

All fertilizer or manure should be injected, incorporated, or applied as close to the ground surface as possible to mitigate NH_3 and odor emissions. Nitrogen applied to crop land is susceptible to volatilization if left on the soil and leaf surfaces, or sprayed from some height above the soil surface. Incorporation of manure immediately after application (within 24 hours) via chisel or irrigation (or precipitation event under 0.15 inches) is suggested for annual crop fields and can reduce ammonia losses by up to 98% (1). Application of manure with an aerator, 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 emissions 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. The sprinkler exposes more manure surface area to the ambient air, allowing a significant portion of the total nitrogen to be volatilized as NH_3 before the liquid manure even reaches the soil surface. Furthermore, sprinkler application also enhances transport and dispersion of emissions especially during windy conditions. Broadcast application, which also exposes manure surface area to the ambient air, also has high NH_3 losses (20 to 30% of total N) if not immediately followed by manure-incorporation.

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 installation of necessary irrigation infrastructure.

<u>Tradeoffs/Limitations</u>: Deep injection of manure decreases NH_3 volatilization, but may

increase N_2O emissions via denitrification.

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

Application of chemical fertilizer and manure nutrients should always be made at agronomic rates to avoid excess application that exacerbates N 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. A nutrient planner can help determine agronomic rate and plan annual applications to match crop needs.

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 rates of emissions are increased. Irrigation to very dry soil can also increase N_2O and/or NH_3 emission by microbial action. Irrigate at recommended levels and timing throughout the growing season.

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 by providing surface cover and nutrient uptake, respectively. Cover crops also reduce nitrate leaching during the wet season by taking up soil nitrate.

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 NH_3 volatilization by binding NH_3 in the aqueous phase and moving it into the soil profile.

IX. Other

1. Installation of Windbreaks or Shelterbelts (NH_3, Odor, PM)

Windbreaks or shelterbelts could be either natural (e.g., a line of trees) or artificial (e.g., a solid brick or hay bale wall). Windbreaks mitigate emissions through multiple pathways.

One, windbreaks break or slow the wind and thus reduces the transport of emitted gases, particulates, and odor from the dairy. A windbreak, composed of trees or a physical barrier, will partially reduce wind speeds for a distance of roughly 30 times its height (17). Two, windbreaks promote mixing and dispersion of emitted gases and odor, which dilute the respective emissions, with respect to the receiver. Three, windbreaks intercept particulates and odor, which subsequently break down as in the case of odorous compounds, or is deposited on site as in the case of particulates. The effectiveness of a windbreak, therefore, depends on its placement, height, spacing or porosity, and prevailing direction of wind and its fluctuations. Windbreak structures ranging even in modest heights ranging from 20 to 30 feet can provide significant mitigation of odor and particulate problems (19). These structures can be installed on individual systems (barns, lagoons, compost or manure piles, etc) in the dairy or on the entire dairy.

Other indirect benefits that accrue from installation of windbreaks, especially of the natural kind include: (i) alleviation of complaints which are sometimes influenced by visual images of the dairy, and (ii) enhanced landscape aesthetics of the dairy.

2. Vehicle Road Condition Management (PM)

Vehicle traffic on on-farm dirt roads can be a significant source of course particulate matter. Feed trucks, manure tankers, maintenance vehicles, etc. are constantly moving around the facility. Watering roads or applying a surface binder can significantly reduce the incidence of PM production from on-farm vehicle traffic. This should be conducted during dry times of the year and during high traffic times.

3. Engine Selection and Efficiency (NOx)

Engines used on-site for power generation should be energy efficient and properly maintained to minimize the production of NOx from combustion processes.

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