CONSERVATION INNOVATION GRANT

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PROJECT GOAL

The purpose of this project was to create a comprehensive BMP plan for reduction of ammonia emissions for cattle producers.

FUNDING RECEIVED AND EXPENDED

Allocated: $286,711
Received: $279,055.41
Expended: $286,709.98

RESULTS

Results of this project are detailed by deliverables in the remainder of this report.

DELIVERABLE #1: COMPREHENSIVE LITERATURE REVIEW OF AVAILABLE AMMONIA BMPS INCLUDING SECTIONS ON NUTRITION, ENGINEERING, AND AGRONOMY

Ammonia Emissions Reduction Best Management Practices (BMP's) for Agricultural Operations

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DEFINITIONS OF MAJOR ATMOSPHERIC POLLUTANTS

Ammonia

Globally, agriculture is the largest source of atmospheric ammonia, with animal agriculture accounting for approximately 40% of the total emissions, and crop agriculture contributing an additional 23% from synthetic fertilizer application and crop emissions (Bowman et al., 1997). Ammonia is the most prominent gaseous species emitted from livestock operations and heavily discussed in the literature from a management and air quality perspective. Ammonia is produced on livestock operations when urea nitrogen in urine combines with the urease enzyme in feces and rapidly hydrolyzes to form ammonia gas. The reaction is quick, taking anywhere from 2-10 hours for ammonia volatilization to peak after mixing of urine and feces (Muck, 1981; James et al., 1999). The quantity and rate of ammonia volatilization depends on a variety of factors such as the amount of crude protein in feed rations, manure management strategies, pH, and climate effects (temperature, relative humidity, etc.), to name a few. Since there is such a large reservoir of ammonia sources (i.e. manure) on livestock operations, there is no shortage of ammonia volatilization potential.

In the summer months, downwind ammonia emissions from a dairy can reach up to 30 parts per million (ppm) (Marcillac et al., 2006), while source emissions (i.e barns, drylots, and lagoons) can be much higher, reaching levels of over 200 ppm in heavily manured areas. High concentrations such as these affect both human and animal health as well as atmospheric visibility. When in gaseous form, ammonia has a short atmospheric lifetime of about 24 hours and usually deposits near its source, contributing to eutrophication of surface waters, soil acidification, and changes in ecosystems (Krupa, 2003). Since ammonia is one of the only basic species in the atmosphere, it readily reacts with strong acidic species in the atmosphere such as nitric and sulfuric acids, which are byproducts of combustion process such as vehicles and industrial emissions, to form ammonium salts, also known as fine particulate matter or $PM_{2.5}$. Due to their small diameter (less than 2.5 microns (µm)) and increased atmospheric lifetime of 15 days, these particulates are able to travel long distances before being dry or wet deposited to the ground surface. This allows them to travel from rural areas to urban locations where they mix and build up in the atmosphere leading to smog and respiratory human health issues.

Ammonia is a highly hydrophilic base that has irritant properties when inhaled which, when combined with water, can injure and burn the respiratory tract (Issley and Lang, 2001). The base form of ammonia, ammonia hydroxide, dissolves in the water of mucus membranes, hydrolyzes and rapidly irritates tissues mainly due to the high pH that results (Zumdahl, 1997). Ammonia can also alter the uptake of oxygen by hemoglobin due to the increase of pH within the blood (Issley and Lang, 2001), which leads to decreased oxygenation of tissues, and decreased metabolic function. When in fine particulate ($PM_{2.5}$) form, ammonium particles pose a great risk to human health. Such small diameter particles are able to be respired and travel deep into lung tissue causing a variety of respiratory ailments such as bronchitis, asthma, coughing, and farmers lung. Due to the side effects of ammonia exposure, Merchant et al. (2003) reported that the current OSHA exposure limit and odor threshold of ammonia is around 50 ppm, but minimal side effects have been noted at this level. However, due to possible cumulative health effects over time, the recommended long term occupational exposure limit of ammonia for agricultural workers is 7 ppm, and 300 parts per billion (ppb) for community exposure (community exposure must be stricter because communities contain very susceptible people such as the elderly and children). At moderate concentrations (50 – 150 ppm), ammonia exposure can lead to eye, throat and skin irritation as well as cough and mucous build up. Prolonged exposure at this level can result in the transfusion of ammonia from the alveoli into the bloodstream and a subsequent disruption of oxygen uptake by hemoglobin. At high concentrations (>150 ppm) ammonia can scar lung tissue, cause lower lung inflammation and pulmonary edema. Exposure to high concentrations of ammonia (500 - 5000 ppm) will cause death in a relatively short time period from prevention of oxygen uptake by hemoglobin (Merchant et al., 2003). These levels are rarely found from livestock operations, but may occur in closed manure storage and poorly ventilated buildings where ammonia concentrations can buildup.

Particulate Matter

Livestock operations and farming practices can be significant contributors to atmospheric particulate matter (PM), also known as dust. Sources of primary particulate matter from farming practices include windblown soil, road dust, and field dust produced from tilling, harvesting, planting, and burning. Sources of primary particulate matter from livestock facilities include feed dust, manure dust, dust from drylots, and road dust. From both a human health and environmental perspective, ammonium salts ($PM_{2.5}$) are the most important particulate species emitted from livestock operations. Ammonium is the ionic (solid or liquid phase) form of ammonia gas. Because it is a basic compound, it is highly reactive with nitric or sulfuric acid, which are emitted from combustion processes, and are present in the air plume around a livestock facility. Ammonium will rapidly react with the acids forming ammonium sulfate preferentially, then ammonium nitrite. These particulate species are known as secondary particulates – compounds formed from the chemical reaction of primary chemical species such as ammonia, hydrogen sulfide, etc. Secondary particulates are major contributors to smog and decreased atmospheric visibility.

Environmentally, fine particulate matter (particles with a diameter $< 2.5\ \mu m$) is a concern for atmospheric visibility and smog in pristine and urban areas. They contribute to smog or haze by absorbing light and creating a visual barrier. Fine particulates can also travel by wind to remote locations and depending on their composition (i.e. ammonium salts), contribute to surface water eutrophication and ecosystem degradation. Studies conducted at Rocky Mountain National Park have found that secondary ammonium particulates and fine particulates ($PM_{2.5}$) have contributed to decreased visibility in the park and soil acidification, causing changes in fragile mountain ecosystems (Baron, 2006).

The most important PM species emitted are those with particle diameters of 10 μm (PM_{10}) and under, which accounts for about one-third of all dust emitted from livestock operations. These particles are able to be respired and deposited in airways, with smaller particles (< 2.5 μm) reaching the lung alveoli and even transfusing into the bloodstream (< 1 μm). The health effects associated with fine PM are well documented and include asthma, bronchitis, coughing, increased mucus production, and increased rates of cardiovascular disease and death. Biologically-derived aerosols (bioaerosols), such as fecal and bacterial origin dusts, may have additional heath effects depending on the composition of the aerosol. Bioaerosols and endotoxins are of concern because they may carry pathogens or other health degrading particles, contributing to respiratory distress and disease (Pell, 1997; Sunesson et al., 2001). These constituents lead to increased rates of asthma, farmer's lung, allergies, cough, dyspnea (difficulty breathing), and development of respiratory disease. The EPA national ambient standard for PM_{10} is 50 $\mu g/m^3$, and 15 $\mu m/m^3$ for $PM_{2.5}$, but no occupational standards exist for endotoxin exposure (Merchant et al, 2003). In communities near livestock operations, these PM exposure levels can be met or exceeded at times. Since the production of dust varies diurnally and seasonally, and exposure varies with wind direction and speed, the exposure to surrounding communities can be variable. Additionally, community exposure to PM is greater the closer one is to a livestock operation because a large portion of dust particles are of larger diameter (> PM_{10}) and tend to dry deposit near their source.

ANIMAL AGRICULTURE BMP'S

Animal agricultural practices emit a variety of emissions including ammonia, nitrous oxide, hydrogen sulfide, volatile organic compounds (VOCs), odor, particulate matter, and methane. Each atmospheric pollutant has its own sources, mitigation techniques, and challenges. Best management practices for reducing emissions from animal agriculture require the consideration of all these relevant gases and a defined reduction goal.

Below, each species is presented along with mitigation strategies, which have been listed due to their demonstrated ability to reduce emissions. From the strategies discussed, the best practices are listed as best management practices (BMP) for suggested use to reduce specific emissions from livestock operations. Additionally, suggestions for further research are presented to help fill some of the gaps in current solutions.

Ammonia

Ammonia emissions from animal agriculture is one of the most studied processes on livestock operations. The emission of ammonia from livestock operations has many secondary effects such as ammonium salt formation ($PM_{2.5}$), wet and dry nitrogen deposition in surrounding areas, soil acidification, water eutrophication, and ecosystem changes (Vitousek et al., 1997). As with many processes, there is a trade-off to reducing ammonia emissions. For instance, by retaining ammonia in one area of the operation, it becomes more susceptible to emission later in the system. If nitrogen is retained in manure, the possibility of nitrate leaching and runoff into ground and surface waters, respectively, increases. Additionally, some management practices that reduce ammonia emissions, such as decreasing pH or encouraging aerobic conditions in manure, can lead to an increase in hydrogen sulfide, odor, or nitrous oxide emissions. To truly eliminate ammonia emission, one must target the source of nitrogen input into the system, or find a way to bind or permanently change the form of ammonia-nitrogen that is emitted in manure.

Nutrition

The easiest and most effective way of reducing ammonia volatilization from a livestock operation is with proper animal feeding and management. Excess nitrogen fed to animals is excreted in the waste and readily volatilized as ammonia. For example, in dairy cattle, up to 70% of the nitrogen consumed is excreted in the manure, with most of that nitrogen, 60 to 70%, excreted in the urine (Todd et al., 2006; Rotz, 2004). Through various management techniques, this excretion amount can be redcued, but the theoretical maximum possible efficiency is 50% nitrogen retention (Rotz, 2004). Beef cattle, swine and poultry all experience a similar deficiency in nitrogen utilization. Swine and poultry may excrete 60% of the total nitrogen consumed, and beef cattle can excrete as much as 80% (Rotz, 2004). Therefore, matching an animal’s nitrogen intake to its maintenance needs is critical in reducing nitrogen excretion.

Since nitrogen excretion is directly related to an animal’s protein intake, crude protein intake needs to be targeted to reduce nitrogen excretion and subsequent ammonia volatilization. Studies have shown that there is a direct link between the amount of crude protein in the diet and the amount of ammonia volatilized from pen surfaces; a reduction in crude protein in the diet leads to a reduction of ammonia volatilization (Todd et al., 2006; Frank and Swensson, 2002). Feeding less crude protein not only reduces the amount of total nitrogen in the manure, but it also changes the partitioning of nitrogen between the urine and feces. Todd et al. (2006) found that steers fed a reduced crude protein diet had 27% more nitrogen in the feces, 28% less nitrogen in the urine, and 44% less total ammonia loss from the manure. Since urinary nitrogen comprises 60 to 70% of the total nitrogen excreted (Todd et al., 2006; Rotz, 2004), and is the main component affecting ammonia volatilization, these results show that decreasing protein intake will decrease the amount of ammonia volatilized from the manure, and maintain more nitrogen in the feces. This can have beneficial effects later in the system when manure is applied to crops. Reducing the amount of protein fed will also decrease the cost of the ration, as protein is usually the most expensive part of an animal’s diet. Additionally, this is a management practice that can be done in any region of the country without special modifications. Compared to other methods of ammonia reduction, reducing the crude protein in an animal’s diet may provide the most cost effective and practical method of reducing ammonia emissions from livestock operations.

For non-ruminant animals, such as poultry and swine, nutritionists aim at feeding an ideal protein in the diet. This is a method that reduces the amount of crude protein fed by matching the animals exact amino acid needs to its intake, reducing the amount of extra nitrogen fed and excreted in the manure. Group or phase feeding is also a practice that helps reduce nitrogen excretion by separating animals into groups by age, sex or stage of growth/production. This allows an animals protein needs to be more precisely matched to their requirements. Since most of the nitrogen excreted is in a form that is easily volatilized as ammonia, any reduction in nitrogen will decrease subsequent ammonia production.

Oscillating protein in the diet has been shown to be an effective means of reducing total N output in ruminants. Oscillating protein works by changing the animal's protein intake amount from a low to a high amount every three days. Cole (1999) found that by oscillating the protein in lamb diets, animals were able to retain more N and excrete less. This is a fairly new method of feeding and still needs further research, but the potential benefits in reducing ammonia appear promising.

Ammonia BMP for Nutrition:

- Reduce the amount of crude protein in the diet to match the animal's needs.
- Practice phase feeding.
- Feed an ideal protein to monogastric animals.
- Practice oscillating protein feeding for ruminants.

Animal

Compared to changes in the diet, relatively small reductions in nitrogen excretion can be made by increasing an animal's production efficiency. Increases in efficiency can be obtained through genetic selection, feed additives, handling, and animal environment changes.

In cattle, production can be increased with the addition of hormones and various feed additives. Bovine somatotropin (bst) injections are given to cattle to increase their milking efficiency, and have been shown to reduce nitrogen excretion by up to 7.8% (Dunlap et al., 2000). However, with growing concern for hormones and pharmaceuticals in soils and water supplies, the use of hormones in livestock is being selected against by consumers.

Proper ventilation in buildings and frequent removal of manure from pen surfaces and floors will help reduce the production of ammonia in an animal's immediate environment leading to healthier and more productive animals.

Ammonia BMP for Animal:

- Increase animal efficiency (e.g. genetic selection, feed additives, etc.).
- Proper building ventilation to improve animal health by removing toxic emissions from the air.

Barns

In dairy barns and enclosed swine and poultry housing, ammonia volatilization occurs soon after manure is deposited on the barn floor. Urine urea nitrogen mixes with the urease enzyme in feces and rapidly hydrolyzes to form ammonia gas. For poultry, this reaction is slightly slower, as they excrete uric acid, which must be converted to urea through aerobic decomposition first. The rate of the reaction is a function of mixing time, temperature, relative humidity, and pH of the manure. Each of these factors can be controlled to some degree in enclosed housing and barns.

The easiest and most effective way to reduce ammonia volatilization from barn floors is by removing manure, which is the source of ammonia emission, at frequent intervals. In dairy systems, the most common type of housing in Colorado is freestall barns. This is where animals are housed in open barns with the ability to move freely in open alleyways between bedded cubicles, provided for resting, and the feeding area. Manure is deposited in the alleyways, which are usually flushed or scraped concrete, and is removed regularly. Since the fresh manure deposition is frequent and mixing rate is increased in these areas, the ammonia volatilization rate is very high in freestall barns. On average, about 16% of the total nitrogen excreted is lost from the freestall area (Rotz, 2004). Modifications to the floor surface can reduce ammonia production potential. A 3% slope channels urine away from feces, reducing the mixing potential and ammonia volatilization by 21% compared to solid level floors (Braam et al., 1997; Zhang et al., 2005). A double sloped floor with a urine gutter in the center that traps and channels urine away from feces was shown to reduce ammonia emissions by 50% compared to solid floors (Braam et al., 1997). The addition of grooves in the concrete floor further aides in channeling urine away from feces, thus reducing ammonia emissions. The removal of manure by scraping or flushing is also used to reduce ammonia volatilization. Studies have found that scraping had little effect on ammonia volatilization potential, as it just spreads and distributes manure over the barn floor surface (Kroodsma et al., 1993; Braam et al., 1997). Rather, flushing alleyways with fresh or recycled lagoon water was shown to remove deposited manure and reduce ammonia emissions by 70% immediately after flushing (Kroodsma et al., 1993). By increasing the rate of flushing from every 4 to every 2 hours, further ammonia reductions were seen (Kroodsma et al., 1993).

Reducing the mixing potential of urine and feces by separating them, decreases ammonia volatilization. Slatted floors that collect and channel manure away have been shown to decrease ammonia volatilization (Zhang et al., 2005). By combining a slatted floor and a slurry channel that is flushed regularly, Hartung and Phillips (1994) saw reductions in ammonia emissions of up to 70%, and Zhang et al. (2005) a 50% reduction over solid floors. An alternative to slatted floors in swine production is a deep litter system. These systems use a deep layer of bedding to separate out urine and feces to reduce ammonia emissions. In the litter, a complex process of aerobic and anaerobic degradation occurs, leading to both nitrification and denitrification processes. Groenestein and Van Faassen (1996) found that while deep layer bedding reduced ammonia by 50% compared to the use of slatted floors, due to denitrification the total nitrous oxide losses were greater with deep litter systems, leading to a more negative environmental impact.

Wet manure usually has a greater potential for ammonia volatilization due to the evaporation potential. By drying manure to less than 40% moisture, both urease activity and ammonia loss are reduced (Sommer and Hutchings, 1995). Management practices such as the use of a manure spreader in drylots, or manure scrapers in barns speed drying. Caution needs to be taken when spreading wet manure, as an increase in manure surface area and air contact will increase the ammonia volatilization potential. The rate of air movement across the surface of the manure also influences the rate of ammonia volatilization by removing the ammonia produced on the surface of the manure, and drawing more ammonia from deeper layers, thus allowing the process to continue.

The use of bedding in freestall dairy barns has been evaluated by Misselbrook and Powell (2005) who looked at six different bedding types typically used in dairy barns (chopped straw, sand, pine shavings, chopped newspaper, chopped cornstalks, and recycled manure solids) and their impact on ammonia emissions. They found that physical structure and relative absorbance capacity were the two most important characteristics influencing ammonia emissions from bedding. The recycled manure was the most absorbent, retaining 15 times more urine than sand, which was the least absorptive. Recycled manure also had the highest rate of ammonia volatilization. They hypothesize this to be because the urine stayed on the top of the manure surface where it was more susceptible to volatilization. With sand bedding, the urine percolated to the bottom of the pile, reducing the urine-air interface and decreasing ammonia emissions. Pine shavings had the second lowest ammonia volatilization rate followed by chopped straw. Chopped newspaper, chopped cornstalks, and recycled manure all had a similar amount of ammonia volatilization.

The rate of ammonia production from manure is very rapid, but can be altered with variations in temperature. Below a temperature of 10º C, urease activity is very low, but activity increases exponentially at higher temperatures (Rotz, 2004; Zhang et al., 2005). At 30º C, essentially all urea in urine is hydrolyzed as ammonia within 6 hours of deposition to the barn floor (Muck, 1981). Smits et al. (1995) found that an increase in animal house temperature from 10 to 24º C resulted in a 46% increase in ammonia emissions. By reducing the temperature in barns, ammonia volatilization can be reduced. Temperature can be controlled with swamp coolers or naturally by allowing more natural ventilation to circulate through bans in the winter months.

Scrubbing exit air from enclosed barns with bio-filters can remove ammonia from the exhaust air and reduce the atmospheric emission from barns (Hilhorst et al., 2002). Proper ventilation through the barn will also help reduce ammonia accumulation in certain areas of the barn. Hinz and Linke (1998) found that ammonia concentration differed by 30% from the center of a swine barn to the outside walls, and that the concentration was highly dependent on ventilation rate.

Ammonia BMP for Barns:

- Flush freestall barns and alleyways regularly with clean or recycled water.
- Use sand bedding in dairy freestalls.
- Provide adequate ventilation in barns to ventilate and cool buildings.
- Scrub exit air from barns.

Drylots

The greatest ammonia emissions occur from the surface of open drylot pens. Due to infrequent manure harvest, volatile ammonia emission from drylots can be up to 70% of the total nitrogen excreted. By increasing the frequency of pen scraping, ammonia volatilization can be reduced.

Since the volatilization of ammonia is dependent on the mixing of urine (urea) and feces (urease), dispersing these events might help reduce ammonia volatilization from drylot pen surfaces. White et al. (2001) found that dairy cows on pasture tended to concentrate elimination behaviors around the water trough during the summer months, as this was where they spent the majority of their time. They concluded that the number of elimination events that occurred in a location was highly correlated with the time spent at the location. Therefore, the deposition of manure (i.e., urine and feces combined) can be affected by the management and layout of the cattle's corral environment. White et al. (2001) suggested designing drylots with water and feed troughs at opposite ends of the corral to distribute manure evenly. Armstrong (1994) recommended placing shade over the center of the corral to encourage cattle to move throughout the corral as the shade moves over the course of the day, again to aid in the distribution of manure.

The pH of the soil surface greatly affects the rate of ammonia volatilization. If the soil is acidic, a pH below 6, ammonia will mainly be found in its ionic form ammonium, and volatilization will be low. At a higher pH, above 8, ammonia will volatilize rapidly from the soil surface. A variety of surface amendments to reduce soil pH have been tested on feedlot and dairy pen surfaces to assess their ability to decrease ammonia emissions. Aluminum sulfate (alum) has been shown to be the most effective additive in reducing the surface pH and ammonia emissions (Shi et al., 2001; DeLaune et al., 2004). In a laboratory study, Shi et al. (2001) found that alum reduced cumulative ammonia emissions by 98% over a 21 day period. They also reported that calcium chloride was an effective amendment, reducing cumulative ammonia emissions by 77%. DeLaune et al. (2004) found that alum was the most effective treatment in reducing ammonia emissions from poultry litter, reducing emissions by 62% over the control. They also concluded that surface application, rather than incorporation was more effective at reducing ammonia volatilization from litter compost piles. Kithorne et al. (1999) found that calcium chloride applied at 20% reduced the ammonia volatilization of poultry manure by 90%, whereas a 20% alum application only reduced ammonia volatilization by 73%. Unlike alum, the calcium chloride treatment works primarily due to microbial inhibition, rather than by reducing pH, thus having a greater impact on the entire manure pile. While surface amendment studies are successful in laboratory settings, they seem to have less success in field application, loosing effectiveness over a short period of time and showing variable results. This is probably due to reapplication of manure on treated pen surfaces and animal hoof action breaking and removing the pen surface crust.

In addition to surface amendments that reduce the pH to reduce ammonia emissions, enzymatic treatments can be used to inhibit the hydrolysis of urine urea to ammonia by the urease enzyme in feces. While enzymatic treatments are not as efficient as acidifiers in decreasing ammonia emissions, Shi et al. (2001) found that enzymatic treatment with the urease inhibitor NBPT (N-(n-butyl) thiophophoric triamide) could reduce cumulative ammonia emissions by 65%. They also found that on a benefit-to-cost ratio, the NBPT treatment to feedlot surfaces was more cost effective than alum treatment, yet it was still an expensive amendment for a producer to install. Varel et al. (1999) found that the addition of NBPT to cattle pen surfaces reduced the amount of ammonia volatilized by retaining the urea in the manure. However, after 11 days they began to see hydrolysis of the urea and subsequent ammonia volatilization and by day 28 all the urea had volatilized as ammonia. They speculated that this was due to chemical breakdown of the urease inhibitors, requiring more frequent application to maintain effectiveness. An efficient, lasting, and cost effective surface amendment to reduce ammonia emissions still needs to be found.

Currently, surface amendments may be effective on a very small scale, but this has little practicality in the current large-scale livestock industry.

Ammonia BMP for Drylots:

- Scrape manure in pens frequently.
- Provide shade for cattle in open lots to encourage movement thought the pens over the course of the day to disperse manure over the pen surface.

Waste Management

Ammonia volatilization from manure is a very rapid process, peaking 10 to 15 hours after excretion with 90% of the total ammonia volatilizing within 26 hours (James et al., 1999). The storage and land application of animal waste is one of the biggest emission sources of both ammonia and odor from dairies. The method of waste management (i.e. composting, lagoons, etc.) used on a farm affects the rate of ammonia emission. The most common method of waste treatment for dairies is an anaerobic lagoon, with 90% of dairies employing a lagoon storage system in the U.S. (Rumburg et al., 2004). This is because lagoons are relativly inexpensive, have very little maintenance, and no treatment costs. Composting of solids has also become a common practice in the livestock industry today, as it is an effective way to treat manure and make it into a usable and more profitable product.

Solid separation. Most livestock operations practice some kind of solid separation prior to storing waste water in the lagoon. During solid separation, the liquid portion of the slurry is removed and the solid portion is left. Often this is composted or stockpiled. The types of solid separation vary, and include screens, earthen pits, leaky dams, and others. On average, producers in Colorado report that their solid separation methods, which vary, will remove between 20-40% of the total solids in the slurry influent. The remaining solids go into the lagoon where they settle to the bottom, or get bubbled to the top of the lagoon surface by methane and carbon dioxide bubbles produced by bacteria in the lagoon, where they form a crust. The manure solids that are removed from the influent usually contain about 25% of the total manure nitrogen, with the remaining 75% of the nitrogen in the liquid portion of the slurry (Rotz, 2004). The more efficient the solid separation method is, the more nitrogen that can be removed in the solid portion of the slurry, and the less that goes into the lagoon. Reducing the amount of solids that go to the lagoon will also help reduce odor since about 40% of odor generating compounds are found in the solids (Zhang and Zhu, 2003).

Lagoons and slurry storage. The rate of ammonia volatilization from lagoons will vary with temperature, nutrient load, pH, the presence of a cover or crust on the surface, and the aerobic/anaerobic status of the lagoon.

After solid separation, 75% of the total nitrogen in collected manure goes into the lagoon with the liquid portion of the influent (Rotz, 2004). At a typical lagoon pH of 7.0-7.6 over all seasons, 60% of the total nitrogen is expected to be volatilized as ammonia (Rotz, 2004). A portion of the remaining nitrogen in solution is either lost as nitrous oxide and nitrogen gas following nitrification/denitrification, or retained in the lagoon as nitrate or other non-gaseous nitrogen compounds (Harper et al., 2000). Since most lagoon effluent is used as flush water for barns, the remaining nitrogen retained in the lagoon water is returned to the barns and usually volatilized as ammonia. Thus, with a recycling system, the nitrogen loss potential is near 100%. If the lagoon water is used for irrigation, this volatilization potential is less (about 50%) due to nitrogen application to fields (Rotz, 2004) and uptake by plants.

If the pH of the lagoon is maintained above 8 (basic), ammonia volatilization increases and ammonia volatilization may be up to 70% of the total nitrogen entering the lagoon (Rotz, 2004). At a pH below 6 (acidic), ammonia is bound in solution in its ionic ammonium form and little ammonia volatilization will occur (Aneja et al., 2001). Achieving a low pH requires the addition of acidifying compounds such as alum, citric acid, and nitric acid to the lagoon. Positive results have been found in reducing ammonia emissions from small-scale waste confinement and laboratory studies, but large scale studies are limited due to cost and feasibility of the method on actual livestock operations. In addition, low pH reduces the efficacy of anaerobic lagoons and increases odor. Finally, the acidic lagoon water can have detrimental effects when applied to crops later. Lefcourt and Meisinger (2001) showed that acidifying agents like alum have been shown to reduce ammonia volatilization from dairy slurry by 58% and soluble phosphorus by 75%, but increased soluble aluminum in solution, which led to soil acidity when slurry was applied to land. They suggested zeoilite as an alternative slurry additive, which was shown to reduce soluble phosphorus and ammonia emissions by 50% by sequestering ammonium-N, which could be a good source of slow-release nitrogen for plants. In Colorado, where soil is generally basic and has a good buffering capacity, the additional acidity of the slurry might not be a huge problem when applied to fields.

An increase in ambient temperature will further increase the rate of ammonia volatilization from waste lagoons (Harper et al., 2000; Aneja et al., 2001; Heber et al., 2002). Aneja et al. (2001) found a strong correlation between ambient temperature and ammonia flux from the surface of swine lagoons. They reported that the greatest emission of ammonia was in the summer months, which was up to 60% of the total yearly flux. Safley and Westerman (1992) found similar results from dairy waste lagoons, noting that the greatest ammonia emissions were in the warmer summer months. Likewise, the lowest ammonia volatilization is in the winter when microbial activity in the lagoon is dormant.

Most animal waste lagoons are anaerobic in nature, and therefore essentially all of the nitrogen entering the lagoon is lost as volatilized ammonia due to nitrification and denitrification processes (Harper et al., 2000). An alternative to anaerobic conditions that would help reduce ammonia volatilization from lagoons is aeration. Aerated lagoons are oxygen-rich and promote the process of oxidation, oxidizing ammonia to nitrate. Aerobic treatment of swine slurry has been shown to reduce odor and total nitrogen by 56% after four days of aeration (Sneath et al., 1992). Even the intermittent use of aerators in swine lagoons has been shown to reduce total nitrogen, odor, and operating costs (Yang and Wang, 1999; Zhang and Zhu, 2005). Rarely, however, are livestock waste lagoons totally aerobic, as aeration is difficult to achieve in a livestock lagoon due to the high solids and protein content in the slurry (Cumby, 1987), and costly energy input. Rumburg et al. (2004) installed commercial aerators in a dairy lagoon and found no change in ammonia emissions stating that the aerators failed to introduce enough oxygen into the lagoon to degrade the ammonia. Due to the high oxygen demand of the nutrient rich solids in a lagoon, it is difficult to provide enough oxygen (1-2 mg/L) to achieve proper aeration in a waste lagoon (Cumby, 1987; Rumburg et al., 2004). The process of aeration can even be counter-productive, raising the pH of the lagoon, and actually inhibiting nitrifying bacteria and promoting ammonia volatilization (Zhang and Zhu, 2003). The best option to reduce ammonia volatilization from lagoons is to have a facultative or stratified lagoon, which has a top layer of aerobic activity to reduce ammonia and odor emission, and a bottom layer of anaerobic activity to promote microbial breakdown of solids and nutrients. This is achieved by mechanical circulation/aeration of the top layers of the lagoon, or can occur naturally in swine lagoons where solids are low, in secondary dairy lagoons, or overflow lagoons with low solids content and nutrient load (Cumby, 1987). It was found that lagoons that were partially aerated or circulated tended to cultivate nitrifying bacterial populations that helped reduce ammonia in the lagoon water by oxidizing ammonia to nitrite and nitrate. In order for this process to take place, the lagoon must be kept at a pH between 7 and 8 to maintain bacterial populations and minimize ammonia volatilization.

The rate of volatilization from the surface of a lagoon relies on 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% (Rotz, 2004), but any cracks in the cover will greatly reduce this efficiency. Misselbrook et al. (2005) found that the formation of a natural crust on the top of lagoons decreases ammonia emissions by up to 50%. The crust development occurs as a result of solids in the lagoon being carried to the surface by methane or carbon dioxide gas bubbles generated by microbial degradation of the organic matter in the lagoon. Evaporation at the surface of the lagoon promotes the drying of the solids and formation of the crust. 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, as in Colorado.

Manure piles and composting. Of the total nitrogen entering manure storage as compost or manure piles, 20 to 50% is lost during ammonia volatilization, and the rest is converted to products of nitrification/denitrification or immobilized. Some nitrous oxide losses occur during nitrification and incomplete denitrification, but these are less than 5% of the total nitrogen loss (Rotz, 2004). Paillat et al. (2005) found that the ammonia flux in compost piles is related to the biodegradable nitrogen present and the nitrification and immobilization of ammonia, which depends on the C:N ratio, the carbon biodegradability, and microbes present in the pile. Less biodegradable carbon sources, like sawdust, were found to increase ammonia emissions, thus the choice of added carbon source to a compost pile will determine the rate of ammonia emissions. Additionally, Paillat et al. (2005) noted that an increase in temperature of the compost pile increased ammonia volatilization from the pile. The amount of manure in the pile will directly affect the rapidity of temperature rise, and thus the ammonia volatilization. They found that the greater the amount of manure in the pile, the faster the temperature rose, but all piles plateaued at the same temperature after two days indicating that a maximum temperature had been reached in all compost piles. In another study, Liang et al. (2006) found that after four days, 90% of the total ammonia had volatilized from the compost pile, which they reported was correlated with the highest temperatures and the greatest amount of aeration of the compost pile. During this period, proper management of pile moisture and air circulation will determine the rate of temperature increase and subsequent ammonia volatilization.

Ammonia BMP for Waste Management:

- Proper confinement of recycled waste water used for flushing barns and alleyways
- Cover lagoon or allow a natural crust to form on top of the lagoon surface.
- Manage solid separation so it maximizes the removal of solids from waste influent.
- Aerate or circulate the lagoon surface.

Particulate Matter

Particulate matter is a concern for both atmospheric degradation and human health. Fine particles ($PM_{2.5}$) arising from livestock operations have been reported to cause an increase in respiratory ailments in humans, and can carry pathogens (Wilson et al., 2002) that could be harmful to human health.

Nutrition

There are no nutritional strategies to improve emission of particulate matter. The only contribution would be to minimize feed dust by storing it in bunkers away from the wind and choosing feedstuffs that do not have a lot of finely ground dust associated with them.

Animal

There are no animal suggestions to improve emission of particulate matter.

Barns

Since most poultry and swine buildings are enclosed, treatment of PM from exhaust air from the building is possible. Additionally, to reduce dust inside barns, proper ventilation needs to be maintained to remove airborne particles. Hinz and Linke (1998) found that peak dust emission in swine barns occurred at feeding, reflecting an increase in animal activity, and the contribution of feed dust to the inside air. To reduce feed dust in enclosed buildings, ventilation rates can be increased during feeding events, or the feed can be treated with some kind of binding compound like fat or molasses to reduce dust emissions from feed.

PM BMP for Barns:

- Maintain proper ventilation in closed buildings to decrease the amount of airborne PM.
- Coat dusty feed with fat or molasses.

Drylots

The moisture content of the pen surface will directly affect the binding of surface manure and soil particles to limit the production of dust. To achieve optimal dust reduction, without increasing odor production, a surface moisture level of 28% has been recommended (Miller and Berry, 2005), with a range of 20 to 41% moisture (Auvermann and Romanillos, 2000). A variety of methods have been suggested to achieve this moisture level including sprinkling, increasing stocking density (Auvermann and Romanillos, 2000), and increasing manure pack depth to increase surface moisture. Each of these methods has its benefits and drawbacks. In the Eastern Plains of Colorado where water is scarce and evaporation rate high, application of water to the pen surface is not practical. Instead, proper pen management and design is the best management tool of choice. Additionally, the application of moisture to the corral surface might increase hydrolysis of nitrogenous compounds on the pen surface to form ammonia (Muck, 1982). This is because ammonia is highly soluble in water and accumulates in wet areas of the corral. When the surface begins to dry, and the water evaporates, approximately 12 % of ammonia volatilizes from manure due to its high oxidation potential and conversion of organic-N to ammonia-N (Voorburg and Kroodsma, 1992).

Peak particulate levels from drylots have been reported in the evening for feedlots reflecting an increase in cattle activity (Mitloehner et al., 2002) and a change in wind patterns (McGinn et al., 2003). Therefore, correlating feeding times with peak animal activity in the evening has been shown to decrease dust generation in cattle feedlots (Mitloehner et al., 2002).

The addition of shade to a pen can reduce dust generation by encouraging animals to spend time in the shaded area, moving with the shade over the course of the day and concentrating their elimination behaviors here (Armstrong, 1994). This will distribute urine and feces over the pen surface, increasing total pen soil moisture and binding particles together (Mitloehner et al., 2002). Mitloehner et al. (1999, 2002) have also shown that heifers provided with shade exhibit less dust-generating behaviors, such as agonistic and bulling behavior, thereby reducing airborne PM potential.

PM BMP for Drylots:

- Maintain a surface moisture content of 28%.
- Feed animals in the evening.
- Provide shade in the pen to distribute manure and increase soil moisture within the pen.

Waste Management

Compost. Compost piles are comprised mainly of dried manure which can be lifted by the wind and carried to downwind locations. The concern with manure dust is that it can contain microbes and pathogens in manure which can be detrimental to human health. The composting process will render pathogens inactive due to the high heat during the compost process (Pell, 1997). This aids in assuring that any airborne dust from compost piles will not adversely affect human health, outside of the effects of dust itself. Keeping compost moist is essential for optimal composting and reduces the potential for dust production from composting sites.

PM BMP for Waste Management:

- Compost manure to reduce pathogens in manure.
- Keep compost moist.

CROP AGRICULTURE BMP'S

Crop agricultural practices emit a variety of emissions including ammonia, nitrous oxide, particulate matter, methane and carbon dioxide. Each atmospheric pollutant has its own sources, mitigation techniques, and challenges. Best management practices for reducing emissions from crop agriculture require the consideration of all relevant gases and a defined reduction goal. Crop-based agricultural practices frequently have contrary effects on differing gases, so no single management practice will effectively reduce all emissions. In crop agriculture, a strategy considering the three most potent greenhouse gases together (carbon dioxide, nitrous oxide, and methane) has generally been adopted. Gaseous emissions, as well as ancillary greenhouse gas production (fuel and fertilizer manufacturing), are combined to produce a Global Warming Potential (GWP) for the management practice. Global warming potential is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale which compares the gas in question to that of the same mass of carbon dioxide (whose GWP by definition is one). Global warming potentials allow management practices to be compared by combining gas emission estimates on a normalized scale. Since nitrous oxide and methane have a higher capability to absorb heat (on a per molecule basis), they have a higher GWP of 300 and 20, respectively, than carbon dioxide. So, small changes in emission of nitrous oxide have large impacts on global warming. Only recently have scientific studies begun to evaluate agricultural management practice impacts on more than one gas using this systems approach in evaluating gaseous emissions.

Below, each species is presented along with mitigation strategies shown to reduce emissions. From the strategies discussed, the best practices are listed as best management practices (BMP) for consideration to reduce specific emissions from agricultural operations. Additionally, suggestions for further research are presented to help fill some of the gaps in the current scientific literature.

Ammonia

Ammonia gas reacts quickly with atmospheric compounds such as sulfuric and nitric acid to form ammonium salts. These salts have a longer atmospheric lifetime than the gas form, and have the potential to spread out over a broad geographic range. Ammonia is either wet, further from, or dry deposited closer to, the areas of emissions (Krupa, 2003). Ammonia emissions contribute to over fertilization, acidification and eutrophication of ecosystems, sometimes at a great distance from their source (Rotz and Oenema, 2006).

Major sources of ammonia emissions in cropland agriculture are volatilization after application of manure and nitrogen (N) fertilizer. Volatilization is a dynamic process and is dependent on the concentration of ammonia in the fertilizer or manure applied to the soil, as well as soil pH, texture, and organic matter. Application of high concentrations of ammonium-based fertilizers or manures will increase ammonia volatilization. Additionally, some application mechanisms, such as broadcast sprinklers, increase contact of manure with the air, and can increase ammonia volatilization.

In contrast, croplands may act as a sink for ammonia dry deposited from feedlots and dairies, as nearby plants take up ammonia through their leaves.

Tillage

Generally, ammonia emissions from cultivated systems without manure additions are low and, therefore, there are no best management practices for ammonia emissions from tillage effects alone. When nitrogen fertilizer is applied to systems with stubble, or surface straw, ammonia emissions increase, due to a 20-times higher urease activity in plant litter than in soil. Consequently, ammonia fertilizer should not be broadcast applied over no-tilled fields, as this could potentially increase ammonia volatilization (Sommer et al., 2004). Moving litter to the side on no-till soil and directly applying urea to the surface may reduce losses (Touchton and Hargrove, 1982).

Ammonia BMP for tillage:

- Apply N fertilizer directly to the soil surface rather than on the top of no-till residue.

N-fertilizer

Ammonia volatilization from soil ranges from 3 to 50% of added N-fertilizer depending on soil texture, cation exchange capacity (CEC), pH, moisture, type of fertilizer added (urea, ammonium nitrate, or ammonium sulfate), and rate of application. According to Fenn and Kissel (1976), there is a negative correlation between soil cation exchange capacity and ammonia volatilization. As cation exchange capacity goes up, the rate of ammonia volatilization goes down, with a minimum of 25 milliequivilents (meq) required in the soil to significantly reduce ammonia loss. Soil pH will also influence ammonium volatilization, as ammonia is converted to ammonium under acidic conditions, decreasing volatilization potential (Krupa, 2003). Loss of ammonia from soils is linearly related to the ammonium content in the soil and increases with increasing temperature (Nelson, 1982).

Urea is the most widely-used fertilizer in the world due to its cheap cost and high nitrogen content. The highest ammonia volatilization rates usually occur from urea application, which typically emits between 6 and 25% of the total fertilizer nitrogen as ammonia. Other fertilizers, such as ammonium nitrate, emit 3%, and calcium ammonium nitrate 5 to 14% (McGinn and Janzen, 1998). Ammonia volatilization from anhydrous ammonia seems to be not only depth, but also soil moisture-dependent, with between 20 and 50% of applied nitrogen lost as ammonia from the soil surface under dry conditions (Sommer and Christensen, 1992). This is because in dry soil, the ammonia retention capacity is low enough to allow ammonia to move through the air-filled pore spaces to the soil surface where it is readily volatilized.

Ammonia-based nitrogen fertilizer may be applied in pellets, or in solution. Granulated forms can be spread evenly and produce homogeneity in application when broadcasted. Liquid application is recommended for situations where ammonia pellets cannot be incorporated into the soil such as pasture or in perennial tree crops. Lightner et al. (1990) found that liquid urea solution could reduce ammonia emission by 35% compared to granular application. Soluble inorganic salts such as calcium chloride or potassium nitrate may by applied with fertilizer to reduce ammonia volatilization (Sommer et al., 2004). Thiosulfate, and in dry conditions, calcium chloride, may reduce the hydrolysis and subsequent volatilization of ammonia. Sulfur applied with ammonium fertilizer may also reduce ammonia volatilization, but may not be useful in all environments.

Hydrolysis, or the process of converting urea to ammonia, is mediated by an enzyme known as urease. Products have been developed that inhibit the process of hydrolysis of urea by urease. Urease inhibitors such as phosphoryl di- and triamides, N-(n-butyl) thiophosphorictramide (NBPT), or phenylphosphorodiamidate (PPD), have been shown to be the most effective in reducing urease activity from applied manure and soils (Byrnes and Freney, 1995). The usefulness of urease inhibitors during dry conditions may be inefficient, because in dry soil, ammonia is allowed to move through the air-filled pore spaces to the soil surface where it is readily volatilized, making urease inhibitors ineffective. When soil is moist and has less cracks following rainfall, application of urease inhibitors may be more useful (Bremner, 1995). The main drawback of urease inhibitors is that they prevent urea in manure and fertilizers from becoming plant available, thus limiting the amount of nitrogen available to plants.

Controlled-release fertilizers can supply nitrogen to plants throughout the growing season and reduce the need for either heavy fertilizer application or multiple fertilizer passes, which are costly to farmers. In a study including controlled-release fertilizers in Colorado, Shoji et al. (2001) found that a single application of controlled release fertilizer at 112 kg N ha^{-1} produced potato yields equivalent to those obtained under N fertilization treatments by basal dressing, topdressing, and fertigation (application of fertilizer in irrigation water), all of which required more fertilizer. Theoretically, by timing controlled use fertilizers with plant demand, less total N fertilizer may be applied.

Since ammonia volatilization is such a rapid process, application methods which increase exposure to the air such as broadcasting over the soil surface, will increase ammonium volatilization. Other methods such as injection of fertilizer or application through irrigation or fertigation are also used. Top dressing and partially covering urea may reduce ammonia volatilization (Bacon et al., 1986). Harrowing stubble before urea application may also reduce ammonia volatilization, as fertilizer is protected from the air in deep cracks, while irrigation or rain will dissolve the fertilizer into the soil. Mixing the soil after fertilizer application is less effective than injecting it to a similar depth, as diffusion will transport the ammonia in the shallow levels of the mixed soil towards the surface.

Loss of ammonia N can be minimized by incorporating the fertilizer or manure into the soil as soon as possible, or by using a controlled-release or stabilized form of urea to amend the soil (Grant, 2005). In calcareous soils, placement between 5 and 7.5 cm is recommended to reduce ammonia emission (Sommer et al., 2004). ,When fertilizer is applied to an actively growing crop in cooler weather (15˚ C or less), losses of ammonia from top dressed urea applications are reduced (Bruulsema, 2005). However, in Colorado, this is not a feasible strategy since not many crops are grown in cool weather.

Ammonia BMP for N-fertilizer type:

- Inject or incorporate fertilizer into soil as soon as possible after application or apply fertilizer in a controlled-release or stabilized form.
- Apply acidic fertilizers with non-precipitating anions (ammonium nitrate or ammonium chloride) to calcareous soils and place as deep as 5 to 7.5 cm.
- Apply monoammonium phosphate, ammonium sulfate, or ammonium nitrate to soils low in calcium.
- Use urease inhibitors to reduce ammonia volatilization.
- Surface apply ammonia fertilizers only to acidic soils to minimize volatilization.

Crops

Crops can either be a sink for ammonia by plant uptake through leaves or deposition on leaf surfaces, or an ammonia source through leaf volatilization or plant residue decomposition (Sommer and Christensen, 1992). Plants can have a significant impact on ammonia transport because they can both absorb and desorb atmospheric ammonia. Under conditions of low soil N or high atmospheric ammonia concentrations, plants absorb ammonia. Under conditions of high soil N or low atmospheric ammonia concentrations, plants volatilize ammonia (Sharpe and Harper, 1995). When atmospheric ammonia concentration exceeds stomatal ammonia concentration, plants absorb a proportional amount of atmospheric ammonia. Additionally, water-soluble ammonia may be stored in moist leaf surfaces (Sommer et al., 2004). Ammonia loss from plants is due to metabolic plant processes such as nitrate reduction, atmospheric N fixation, photorespiration in leaves, and transport of nitrogen products within the cell. Ammonia uptake in natural systems, pastures (Cowling and Lockyer, 1981), and cropped lands adjacent to animal feed yards, has been found to be significant.

Volatilization of ammonia may also occur at the end of the growing season when plant tissue dries, perhaps due to chlorophyll degradation. Due to the spatial variability in the plant where these processes occur, ammonia volatilization is subsequently difficult to predict (Sommer et al., 2004). When plant material is degraded by soil microbes, ammonia can be volatilized. Losses range from 3.1 kg N ha^{-1} to 12.6 kg N ha^{-1} per year from sugar beet and potato shoots with high leaf N content.

In a summary of available European literature, Sommer et al. (2004) found that ammonia loss for wheat, barley, and oil seed rape over 2 growing seasons was between 1 and 5 kg NH_3-N $ha^{-1}yr^{-1}$, representing between 1 and 4% of applied N. Nitrogen loss was higher under greater foliage N concentration. Ammonia volatilization from winter wheat in the western US has been measured to be 15 kg NH_3-N $ha^{-1}yr^{-1}$ (Harper et al., 1987). Sommer et al. (2004) concluded that agricultural plant communities are a significant net ammonia source to the atmosphere ranging from 1 to 15 kg NH_3-N $ha^{-1}yr^{-1}$ depending on plant species and climatic conditions.

Ammonia BMP for crops:

- Generally ammonia volatilization from crops may be significant, but further research is required to verify this result as well as to determine effective best management strategies.

Pastures

The majority of ammonia losses on pasture are from urine (55 to 75%) (Van Horn et al., 1996), while emissions from feces are only about 5% of total fecal nitrogen (Rotz, 2004). Higher rates of ammonia loss from urine are associated with an increased level of protein in the animal's diet (Todd et al., 2006). By matching an animals protein needs to its intake, excess urinary nitrogen excretion can be reduced. Avoiding overgrazing with proper pasture management will help reduce the amount of ammonia emitted from urine spots by increasing plant cover and nitrogen uptake. Soil conditions will also influence ammonia volatilization with greater rates of emission occurring during dry, hot weather (Jarvis et al., 1989). Precipitation decreases ammonia volatilization by binding ammonia in the aqueous phase and moving it into the soil (Rotz, 2004). Rapid infiltration into the soil may also reduce emissions by quickly moving the nitrogen into the soil and deceasing air contact time.

Since the volatilization of ammonia is dependent on the mixing of urine (urea) and feces (urease), dispersing these events even over a pasture surface might help reduce ammonia volatilization. White et al. (2001) found that dairy cows on pasture tended to concentrate elimination behaviors around the water trough during the summer months, as this was where they spent the majority of their time. They concluded that the number of elimination events that occurred in a location was highly correlated with the time spent at the location. Therefore, the deposition of manure (i.e., urine and feces combined) can be affected by the management and layout of the cattle's pasture environment. White et al. (2001) suggested designing corrals with water and feed troughs at opposite ends of the corral to distribute manure evenly. In a pasture situation, this method can be utilized by moving the water trough and feed stations to a new location every few days to disperse cattle activity and manure deposition.

Ammonia BMP for pastures:

- Feed protein to match the animal's requirements to reduce excess urinary nitrogen output.
- Stock only the appropriate number of animals on pasture to avoid overgrazing pastures.
- Move water and feeding areas on a regular basis to spread urine and feces deposits over the field.
- Irrigating may reduce ammonia emissions immediately after grazing, but could increase emissions of nitrous oxide and groundwater contamination with nitrate.

Manure Additions

Climatic variables. Temperature, humidity, wind speed, and precipitation all influence the rate of ammonia volatilization. Ammonia loss increases exponentially with temperature (Sommer, 2001), and increases with increasing wind speed up to about 2.5 meters per second. Therefore, the application of manure during cool weather will decrease the amount of ammonia volatilized from the manure (Amon etal., 2006). Precipitation also decreases ammonia volatilization by binding ammonia in the aqueous phase and moving it into the soil (Rotz, 2004).

Ammonia BMP for climate:

- Manure application should occur during cool weather and on still rather than windy days whenever possible.
- Water additions, such as irrigation or precipitation, could reduce ammonia volatilization, but may increase nitrate leaching and nitrous oxide emissions.

Manure characteristics. Manure composition varies between animal species and manure type, which is characterized by the method of manure storage. Manure may be stored either in solid form (greater than 15% dry matter), slurry form (7-15% dry matter), or as a liquid (less than 7% dry matter). Solid manure storage is typical for drylot operations or when bedding is used to absorb manure. Slurry is commonly used on dairies where feces, urine and wash water are combined. Liquid storage in lagoons is common on large dairy, swine, and poultry production operations (Rotz, 2004). It is important to note that storage options that reduce ammonia emissions frequently only retain ammonia as nitrogen in manure, and after field application, it is often volatilized (Amon et al., 2006).

Manure slurry generally has a greater ammonia volatilization potential than drier forms, although if not incorporated into soil, both types may have similar total nitrogen losses over time (Rotz, 2004). Sommer and Hutchings (1995) found that between 30 and 70% of slurry nitrogen volatilized as ammonia within the first 6 to 12 hours of storage, then the ammonia volatilization rate decreases rapidly, while drier manure, such as poultry manure, generally had lower total ammonia loss. This could be because ammonia loss from poultry manure involves an extra step as uric acid must first be converted into urea before it is available for volatilization. This reaction is controlled by water availability and temperature (Sommer et al., 2001).

Ammonia volatilization from applied slurry is related to the slurry dry matter content and is dependent on the pre-treatment of the manure before application. Ammonia volatilization is generally proportional to the ammonia content of the manure, and generally increases with increasing dry matter content up to 12% (Rotz, 2004). The lower the dry matter content, the more quickly the slurry infiltrates into the soil (Rotz, 2004). However, lowering the dry matter content by 50% (or diluting the manure) will double the amount of manure handled, since liquid addition will increase volume of manure.

Slurry pre-treatment before application may reduce ammonia emissions after the slurry is applied, but to fully consider any benefit, the processes must be considered together. In a comparison of manure pretreatment on ammonia volatilization after application (40 m^3 ha^{-1}), Amon et al. (2006) found that the majority of ammonia emission occurred during application of slurry rather than storage. The amount of ammonia volatilizaed during field application was directly correlated to the amount of ammonia that was retained during storage. The less ammonia emitted during the storage period, the more ammonia that was emitted during field application. Of the storage methods, the liquid portion of separated manure (manure with solids mechanically removed) had the highest ammonia volatilization of 81% during storage, followed by aerated dairy slurry which emitted 50% during storage. Consequently, separated manure slurry had the lowest ammonia volatilization during application of 19%..The other manure treatments including anaerobic digestion, aerated, and untreated slurry had greater than 50% of the ammonia emissions volatilize after surface application through band spreading simulation. When both field and storage emissions were considered together, the untreated manure and anaerobically digested manure had the lowest total ammonia emissions (226.8 and 229.9 g NH_3 per m^3), while the emissions from separated and aerated treatments were nearly double that (402.9 and 422.0 g NH_3 per m^3). Authors noted that aeration can reduce the dry matter content of the slurry, thus reducing volatilization, but the total nitrogen lost in the aeration process counteracts the reduction in loss of applied nitrogen.

Reducing manure pH is another method for reducing ammonia volatilization (Sommer and Hutchings, 1995). By dropping the pH below 6.5 with sulfuric or nitric acid treatments, ammonia emissions were reduced up to 75%. Acidification can also be achieved by amendments of alum or ferrous sulfate (Rotz, 2004). However, over application of acidified manure to soils may decrease the soil pH. Initially, the soil will buffer the pH change causing little impact on plant growth, but eventually a pH change will occur and may decrease crop productivity. No economic feasibility studies were found to demonstrate the possibility of implementing this technology to reduce volatilization.

Ammonia BMP for manure characteristics:

- Following agronomic rate recommendations, apply liquid slurry onto soil surface as quickly as possible to minimize storage time and maximize soil infiltration which reduces volatilization.
- Digested slurry and liquid manure should be applied to soils during cool weather with low trajectory such as drop nozzles for liquid slurry.

Manure application methods. Manure is applied to soils by overhead irrigation, broadcast spreading, band spreading, trail hose, or injection. The application method chosen depends on the method of storage; solid, slurry, or liquid and on farm equipment availability. Next to irrigation, broadcast spreading with a splash plate is the cheapest method of applying both slurry and liquid manures, while solid manures are applied with a broadcast spreader (Sommer and Hutchings, 2001). Since ammonia volatilization from liquid manure is dependent on the surface-air interface, reducing the size of slurry droplets will increase ammonia volatilization by increasing the surface area of the droplets exposed to the air (Sommer and Hutchings, 2001). Practices aiming to reduce ammonia volatilization during liquid application of slurry should therefore reduce the exposure time and increase the size of the droplets.

In a summary of studies investigating ammonia loss using various application methods, Rotz (2004) found that overhead irrigation (i.e. sprinklers) generally had the highest rate of ammonia volatilization. With sprinkler irrigation, a portion of the total nitrogen is volatilized in the air as ammonia before the liquid manure even reaches the soil surface. Broadcast application of slurry and cattle or swine manure also had high losses of ammonia (20 to 30% of total N). These rates of loss, however, were highly variable with application to grassland verses heavy crop residues, which tended to increase ammonia loss by 30 to 50% due to increased urease activity in plant residues compared to soil. Band spreading is an alternate form of manure application and is primarily used on grasslands or on established crops. With well-formed bands, nitrogen loss can be reduced by 30 to 70% compared to broadcast spreading. However, studies which had bands covering more surface area have been less effective (Rotz, 2004).

Due to the volatile nature of ammonia, incorporation of slurry into the soil immediately after application is the most effective means to reduce ammonia emissions (Malgeryd, 1998; Sommer and Hutchings, 2001), and the deeper the incorporation, the less the emissions (Sommer and Hutchings, 2001). Slurry injection is the most effective method of incorporation for reducing N loss both during application and afterward (Rotz, 2004). Rotz (2004) found that application of slurry by shallow and deep injection (>10 cm depth) had the lowest ammonia loss (8 and 2%, respectively), but deep injection may cause root damage in grassland or established crops. Open slot injection leaves some slurry uncovered, which may increase ammonia volatilization. In a recent study of injection techniques, Rodhe et al. (2006) found that injection in closed slots resulted in no detectable ammonia emissions. However, due to increased nitrogen retention by the soil and low oxygen conditions at the injection site, injection may cause greater leaching and denitrification if application is not timed with maximum crop uptake.

Ammonia BMP for liquid, slurry, and solid application:

- Minimize liquid manure application by broadcast sprinkler irrigation.
- Avoid broadcast spreading of manure on grasslands or soils with crop residues. Instead band slurry in established crops when possible.
- Inject liquid or slurry manure to an appropriate root depth when soil moisture is favorable to minimize volatilization.
- Incorporate manure into the soil as soon after application as possible to reduce the air surface exposure time.

Timing of manure application. The ideal solution to reduce nitrogen loss is to time manure application with the time of intense crop nitrogen demand so nitrogen is captured by the plant rather than lost via volatilization or through nitrate leaching (Van Horn et al., 1996; Rotz, 2004). Manure and soil should always be analyzed for nutrient content prior to application to crop lands to match nutrient needs with application rates.

Studies in New Zealand found that autumn application of manure on fallow land can loose between 50 and 70% of nitrogen through nitrate leaching (Di and Cameron, 2002). Large amounts of excess N in the soil may be lost via dentirification. Denitrification inhibitors have been used to mitigate this emission with mixed success (Rotz, 2004). In Europe, economic as well as environmental benefits have resulted from timed manure application by reducing mineral fertilizer application costs and leaching, although this benefit is small compared to the cost of injection (McGechan and Wu, 1998). Application during the coolest part of the day or when rain is expected, and when wind speed is low may also reduce ammonia emissions, but its effectiveness is highly dependent on farmer flexibility, the amount of manure to be applied, and the length of time available for application. However, if a rain event occurs immediately following manure application, the potential for runoff in increased, unless the manure is injected or incorporated into the soil.

Further research is necessary to determine the physical, biological and chemical processes involved in ammonia release under farm conditions. More specific information is necessary regarding ammonia emissions from various manure types ,and farm-level emission data for ammonia model emission validation is also required. Multi-year emissions studies from land application would also be beneficial.

Ammonia BMP for animal waste:

- Analyze manure and soil prior to application to match application rates with crop requirements and soil type.
- If possible, time manure application to reduce nitrogen loss by feeding plants when the nutrients are in demand. This practice is limited to liquid manures, as solids are harder to control due to mineralization.
- Manure should be applied during cool weather and on days with minimal wind.

Particulate Matter

Particulate matter (dust) loss is caused by natural processes, such as wind erosion, and is common in semi-arid environments such as the Great Plains. Over 60% of wind erosion in the U.S. occurs in the Great Plains. Agricultural practices that disturb the soil increase the amount of particles released into the air. Once airborne, these particles negatively influence air quality and have been linked to respiratory illnesses in humans including asthma and lung disease (Nordstrom and Hotta, 2004). This is of concern because concentrations of dust associated with farming may exceed regulatory standards for human health.

Particulate matter from both dairies and feedlots contributes significant amounts of dust to adjacent cropland, which can considerably alter nutrient budgets for phosphorous and nitrogen compounds in the soil (Rogge et al., 2006). A 30-year long study of adjacent shortgrass steppe downwind from an established feed yard, found dry deposition to average over 2 tons of dust per hectare per year (Todd et al., 2004). The authors estimated this dust contained a significant amount of nitrogen (20-30 kg N ha^{-1}). They attributed vegetation shift from perennial to annual grasses to increased dry deposition of nitrogen and phosphorous.

Cropland

Particulate matter emissions result from agricultural activities such as tilling, leveling beds, planting, weeding, seeding, fertilizing, harvesting, mowing, cutting, baling, spreading manure or compost, applying herbicides, and burning fields (Nordstrom and Hotta, 2004). Generally, there is a fair amount of research on dust emissions from agricultural operations; however, specific quantification of agricultural contributions to dust emissions is difficult. This is because the chemical composition of soil dust from agricultural fields and from natural systems are undifferentiated due to the similarity of their elemental compositions (Rogge et al., 2006).

Particulate matter emission depends on climatic factors, soil properties, surface characteristics, ground cover, and agricultural management practices. Due to climatic constraints, land-use should be appropriate, and marginal lands should be avoided. Wind speed and direction directly influence the amount of soil erosion that occurs, while temperature and humidity may play indirect roles. Soil which has good structure is less prone to wind erosion. Surface characteristics of the soil such as roughness, surface crusting and moisture all influence the amount of wind erosion by influencing wind patterns along the soil surface. Strategies that decrease wind erosion will generally decrease dust or particulate matter loss.

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 will partially reduce wind speeds for a distance of roughly 30 times its height (Borrelli et al., 1989). Strip cropping, or leaving the standing plant residue in strips throughout the field, can function as a wind break. Cover crops can also reduce the amount of surface exposed as well as provide root structures to hold soil in place. Use of cover crops instead of bare-fallow decreases wind erosion as well as building soil carbon However, during the 1970s, many old windbreaks may have been removed to install larger machinery, irrigation systems, or to create larger fields (Black and Siddoway, 1971) thus increasing the potential for wind erosion.

Soil tilling increases surface roughness, which may decrease wind erosion in the short term, but over the long-term, dry, disturbed soils have less soil structure, and are more susceptible to erosion. Tillage is less effective than cover crops, but is less costly and may be preferred in semi-arid regions where economically viable crops do not produce substantial residue, and where the cover crops can thrive on the minimal water supply (Fryrear, 1985). Reducing tillage through conservation tillage maintains residue cover on the soil surface during the non-growing season. Manure application to no-till treatments has been shown to increase surface residue and can reduce erosion as well (Woodruff et al., 1974).

Particulate matter BMP for cropland:

- Use windbreaks to reduce wind speed.
- Reduce field traffic.
- Reduce tillage.
- Use cover crops rather than bare-fallow field management.

DELIVERABLE #2: EVALUATION OF EFFECTIVENESS AND COST OF AMMONIA BMPS ON-FARM

Agricultural NH_3 emissions contribute to N deposition in Rocky Mountain National Park. Increased nitrate levels in alpine lakes and shifts in plant communities in the Park have been related to increasing levels of N deposition. The agricultural community is expected to voluntarily adopt Best Management Practices (BMPs) that will reduce NH_3 emissions. Our goal was to evaluate the impact of BMPs on NH_3 emissions from feedlots and dairies to provide producers with information to make choices that are both economically and environmentally sustainable.

Following a thorough literature review, the most promising BMPs were tested on feedlots and dairies to measure their real-world efficacy, practicality and implementation cost. Selected BMPs were tested on 6 dairy and 6 feedlot operations in 2007 and 2008. The 12 BMPs tested were: bedding, alum application to pen surfaces, feedlot pen manure removal frequency, freestall manure removal technology, natural vs. conventionally fed cattle, freestall manure removal rate, water application to drylots, composting vs. stockpiling of manure, feed additives, in-pen v.s out-of-pen manure stockpiling, harrowing woodchips into drylots, and natural lagoon covers. Ammonia concentration was measured from surfaces using a real-time NH_3 analyzer (Nitrolux-S, Pranalytica) with eight coincident measurements per sample location (replications varied by BMP).

Results for individual BMP sampling models were analyzed using the mixed model procedure accounting for day and weather effects. Significance was evaluated at $P=0.10$ using lsmeans. Compost bedding in freestalls had 43% lower NH_3 concentration above the bedding surface than sand over a 30 day period ($P=0.06$). Harrowing wood chips into drylots tended to decrease ammonia concentration by 40% ($P=0.19$). Alum application to feedlot pen surfaces was not economical (~$43/head/yr), and had limited long-term effectiveness (56% reduction for 2 days). Surface emissions from naturally vs. conventionally fed cattle were not different ($P=0.51$). Extension materials will be developed to aide feedlot and dairy managers in their management decisions. Results, by operation, are detailed below.

La Luna Dairy

BMP: Sand vs. Compost Bedding; Sand vs. Compost vs. Wood Bedding; Pre vs. Post Scrape

Table 1. Summary of freestall bedding treatments: sand vs. compost. The top values show the summary of all test sites, while the bottom values show the results for your dairy. At your dairy, we found that sand bedding had lower ammonia emissions than compost. This was a common result when sand was new, as was the case at your dairy. Old sand (>1 yr), tended to have higher ammonia emissions than compost bedding, which tended to be relatively constant across all test sites.

Trt[1]	Mean	SEM[2]	n[3]	Min	Max	*P*-value
Sand	**6.95**	0.71	236	2.50	29.15	<0.0001
Comp	**5.37**	0.75	261	1.13	14.53	<0.0001
Sand vs. Comp (all sites)						**0.0311**
Sand -LL	**2.35**	1.66	50	0.59	3.74	0.1773
Comp -LL	**4.90**	0.76	44	3.41	6.14	<0.0001
Sand vs. Comp (La Luna)						**0.3542**

[1] Trt=Treatment (sand or compost bedding).

[2] SEM = Standard error on the mean. Shows the variation within the values measured.

[3] n=Total number of measures taken.

Table 2. Summary of freestall bedding treatments: sand vs. compost vs. wood shavings measured at your dairy (La Luna). Results showed that sand and wood shavings had a similar ammonia volatilization rate, while compost tended to have a greater ammonia emission potential.

Trt	Mean	Sig[1]	SEM	n	Min	Max	*P*-value
Sand	**2.25**	**a**	0.22	51	0.59	3.74	0.0028
Compost	**4.89**	**b**	0.22	44	3.41	6.14	0.002
Wood	**2.13**	**a**	0.20	43	1.30	3.49	0.0009
Sand vs. Compost vs. Wood							**0.0048**

[1] Sig = Significance. Values with the same letter are not significantly different from each other.

Table 3. Summary of ammonia concentration from freestall alleyways before and after manure removal by scraping. Results for all dairies measured showed that ammonia tended to increase in the 40 minutes after scraping before decreasing to pre scrape levels.

Trt	Mean	SEM	*P*-value
Pre	6.85	0.17	<0.0001
Post	7.67	0.27	<0.0001
Pre vs. Post			**0.2012**

Empire Dairy

BMP: Sand vs. Compost Bedding; Pre vs. Post Scrape; Wood in Drylot

Table 1. Summary of freestall bedding treatments: sand vs. compost. The top values show the summary of all test sites, while the bottom values show the results for your dairy. At your dairy, we found that your sand bedding tended to have lower ammonia emissions than sand or compost at other sites. This was a common result when sand was new, as was the case at your dairy. Old sand (>1 yr), tended to have higher ammonia emissions than compost bedding, which tended to be relatively constant across all test sites.

Trt[1]	Mean	SEM[2]	n[3]	Min	Max	*P*-value
Sand	**6.95**	0.71	236	2.50	29.15	<0.0001
Comp	**5.37**	0.75	261	1.13	14.53	<0.0001
Sand vs. Comp (all sites)						**0.0311**
Sand (E)	4.10	1.31	39	1.14	9.67	0.0047

[1] Trt=Treatment (sand or compost bedding).
[2] SEM = Standard error on the mean. Shows the variation within the values measured.
[3] n=Total number of measures taken.

Table 2. Summary of ammonia concentration from the surface of drylot pens with or without the addition of wood chips to the pen surface. The top results (blue) show the summary of all test sites, while the bottom values (green) show the results for your dairy. The addition of wood chips to the pen surface significantly reduced ammonia volatilization. These results were seen at your dairy as well as all test sites.

Trt	Mean	SEM	n	Min	Max	*P*-value	C:N[1]
Wood	**2.33**	0.74	46	1.09	3.84	0.001	26.5
No-Wood	**6.54**	0.74	35	3.98	9.36	0.0366	13.5
Wood vs. No-Wood						**0.0168**	
Wood - E	2.36	0.28	17	1.33	3.26	0.0181	27
NoWood - E	7.56	0.28	29	6.63	9.36	0.0112	15
Wood vs No-Wood (Empire)						***0.0152***	

[1] C:N = Carbon to nitrogen ratio. The higher the ratio, the harder it is for ammonia to volatilize.

Table 3. Summary of ammonia concentration from freestall alleyways before and after manure removal by scraping. Results for all dairies measured showed that ammonia tended to increase in the 40 minutes after scraping before decreasing to pre scrape levels.

Trt	Mean	SEM	*P*-value
Pre	6.85	0.17	<0.0001
Post	7.67	0.27	<0.0001
Pre vs. Post			**0.2012**

Badger Creek/Quail Ridge

BMP: Sand vs. Compost Bedding; Pre vs. Post Scrape; Wood in Drylot

Table 1. Summary of freestall bedding treatments: sand vs. compost. The top values show the summary of all test sites, while the bottom values show the results for your dairy. At your dairy, we found that your compost bedding tended to similar results to other compost facilities. Sand bedding, particularly old sand (>1 yr), tended to have higher ammonia concentrations than compost, which tended to be relatively constant across all test sites.

Trt[1]	Mean	SEM[2]	n[3]	Min	Max	*P*-value
Sand	**6.95**	0.71	236	2.50	29.15	<0.0001
Comp	**5.37**	0.75	261	1.13	14.53	<0.0001
Sand vs. Comp (all sites)						**0.0311**
Comp (Q)	5.68	0.62	30	3.09	7.39	<0.0001

[1] Trt=Treatment (sand or compost bedding).

[2] SEM = Standard error on the mean. Shows the variation within the values measured.

[3] n=Total number of measures taken.

Table 2. Summary of ammonia concentration from the surface of drylot pens with or without the addition of wood chips to the pen surface. The top results (blue) show the summary of all test sites, while the bottom values (green) show the results for your dairy. The addition of wood chips to the pen surface reduced ammonia volatilization. These results were seen at your dairy as well as all test sites.

Trt	Mean	SEM	n	Min	Max	*P*-value	C:N[1]
Wood	**2.33**	0.74	46	1.09	3.84	0.001	26.5
No-Wood	**6.54**	0.74	35	3.98	9.36	0.0366	13.5
Wood vs. No-Wood						**0.0168**	
Wood	2.38	0.31	29	1.09	3.84	0.0832	26
NoWood	4.45	0.42	6	3.98	5.12	0.0032	12
Wood vs No-Wood (Badger)						***0.0842***	

[1] C:N = Carbon to nitrogen ratio. The higher the ratio, the harder it is for ammonia to volatilize.

Table 3. Summary of ammonia concentration from freestall alleyways before and after manure removal by scraping. Results for all dairies measured showed that ammonia tended to increase in the 40 minutes after scraping before decreasing to pre scrape levels.

Trt	Mean	SEM	*P*-value
Pre	6.85	0.17	<0.0001
Post	7.67	0.27	<0.0001
Pre vs. Post			**0.2012**

Aurora Dairy

BMP: Sand vs. Compost Bedding; Pre vs. Post Scrape

Table 1. Summary of freestall bedding treatments: sand vs. compost. The top values (blue) show the summary of all test sites, while the bottom values (green) show the results for your dairy. At your dairy, we found that sand bedding had higher ammonia emissions than compost. This was a common result when sand was old, as was the case at your dairy. Old sand (>1 yr), tended to have higher ammonia emissions than new sand or compost bedding, which tended to be relatively constant across all test sites.

Trt[1]	Mean	SEM[2]	n[3]	Min	Max	*P*-value
Sand	**6.95**	0.71	236	2.50	29.15	<0.0001
Comp	**5.37**	0.75	261	1.13	14.53	<0.0001
Sand vs. Comp (all sites)						**0.0311**
Sand - A	**9.20**	1.10	115	2.50	29.15	<0.0001
Comp - A	**4.89**	0.53	161	1.13	14.53	<0.0001
Sand vs. Comp (Aurora)						***0.0372***

[1] Trt=Treatment (sand or compost bedding).
[2] SEM = Standard error on the mean. Shows the variation within the values measured.
[3] n=Total number of measures taken.

Table 2. Summary of ammonia concentration from freestall alleyways before and after manure removal by scraping. Results for all dairies measured showed that ammonia tended to increase in the 40 minutes after scraping before decreasing to pre scrape levels.

Trt	Mean	SEM	*P*-value
Pre	6.85	0.17	<0.0001
Post	7.67	0.27	<0.0001
Pre vs. Post			**0.2012**

Diamond D Dairy

BMP: Sand vs. Compost Bedding; Pre vs. Post Scrape

Table 1. Summary of freestall bedding treatments: sand vs. compost. The top values (blue) show the summary of all test sites, while the bottom values (green) show the results for your dairy. At your dairy, we found that sand bedding had higher ammonia emissions than compost. This was a common result when sand was old, as was the case at your dairy. Old sand (>1 yr), tended to have higher ammonia emissions than new sand or compost bedding, which tended to be relatively constant across all test sites.

Trt[1]	Mean	SEM[2]	n[3]	Min	Max	*P*-value
Sand	**6.95**	0.71	236	2.50	29.15	<0.0001
Comp	**5.37**	0.75	261	1.13	14.53	<0.0001
Sand vs. Comp (all sites)						**0.0311**
Sand	9.78	1.53	32	6.14	19.39	<0.0001
Comp	4.97	0.69	26	3.86	6.15	<0.0001
Sand vs. Comp (Diamond D)						**0.0012**

[1] Trt=Treatment (sand or compost bedding).
[2] SEM = Standard error on the mean. Shows the variation within the values measured.
[3] n=Total number of measures taken.

Table 2. Summary of ammonia concentration from freestall alleyways before and after manure removal by scraping. Results for all dairies measured showed that ammonia tended to increase in the 40 minutes after scraping before decreasing to pre scrape levels.

Trt	Mean	SEM	*P*-value
Pre	6.85	0.17	<0.0001
Post	7.67	0.27	<0.0001
Pre vs. Post			**0.2012**

Five Rivers Feedlot

BMP: Compost vs. Stockpile

Table 1. Summary of manure treatment techniques: compost and stockpiling, over time. Color numbers indicate the same pile over various test dates.

	8/22/2008		8/29/2008		9/4/2008			9/17/2008	
Pile ID	**AVG**	**VAR**	**AVG**	**VAR**	**AVG**	**VAR**	**C:N**	**AVG**	**VAR**
Old STK (>6 months)	10.07	15.37	-	-	-	-	-	-	-
Fresh STK (Just out of Pens)	35.25	12.56	37.90	25.46	-	-	-	44.34	26.31
Fresh STK (3-5 days old)	-	-	46.89	212.65	8.66	5.96	-	-	-
Fresh COM (<7 days old)	-	-	38.79	273.75	-	-	-	54.02	69.28
Medium COM (14 d)	-	-	-	-	40.14	61.26	14	84.10	140.72
Aged COM (30-50 days old)	24.05	30.57	35.66	341.50	27.25	100.98	13	40.22	138.64
Finished COM (>60 days)	6.07	0.59	28.87	5.08	11.65	0.35	13	11.96	0.21
Finished Com (from '06)	4.39	0.44	2.55	0.33	3.43	0.38	-	1.24	0.19

Magnum Feed Yard

BMP: Nat vs. Con

Table 1. Summary of naturally (without feed additives) vs. conventionally (with fed additives) fed cattle. The top values (blue) show the summary of all test sites, while the bottom values (green) show the results for your feedlot. The two treatments were not significantly different than each other, but naturally fed cattle showed a lower ammonia volatilization rate from the pen surface.

Trt[1]	Mean	SEM[2]	n[3]	Min	Max	*P*-value
Nat	**3.75**	0.84	110	1.12	7.75	0.001
Con	**4.29**	0.80	111	1.25	14.35	0.003
Nat vs Con						**0.5067**
Nat - Mag	3.43	1.07	61	1.62	6.58	0.0147
Con - Mag	4.12	0.93	74	1.25	14.35	0.0029

[1] Trt=Treatment (sand or compost bedding).

[2] SEM = Standard error on the mean. Shows the variation within the values measured.

[3] n=Total number of measures taken.

Cargill Feeders

BMP: Alum

Table 1. Summary of the application of granular or liquid to the surface of feedlot pens. Results showed a significant decrease in ammonia volatilization immediately following alum application, but one day later, ammonia emission rates were as high or higher than pre application rates showing that alum is not effective an effective means of reducing ammonia volatilization long term.

Trt[1]	Day[2]	Mean	SEM[3]	n[4]	Min	Max	*P*-value
Granular	d0 Pre-App	4.54	0.27	7	4.01	4.73	<0.0001
	d0 Post-App	1.72	0.17	17	1.31	2.07	<0.0001
	d1 Post-App	3.06	0.16	19	2.19	4.16	<0.0001
Liquid	d0 Pre-App	2.29	0.22	10	1.19	2.85	<0.0001
	d0 Post-App	1.04	0.18	16	0.90	1.13	<0.0001
	d1 Post-App	4.42	0.17	17	1.56	6.20	<0.0001

[1] Trt=Treatment (sand or compost bedding).
[2] Day = The day of measurement (do is the day of application, d1 is the day after application).
[3] SEM = Standard error on the mean. Shows the variation within the values measured.
[4] n=Total number of measures taken.

Bamford Feedyard

BMP: Nat vs. Con; Pre vs. Post Pen Scrape

Table 1. Summary of naturally (without feed additives) vs. conventionally (with fed additives) fed cattle. The top values (blue) show the summary of all test sites, while the bottom values (green) show the results for your feedlot. The two treatments were not significantly different than each other, but naturally fed cattle showed a slightly lower ammonia volatilization rate from the pen surface.

Trt[1]	Mean	SEM[2]	n[3]	Min	Max	*P*-value
Nat	**3.75**	0.84	110	1.12	7.75	0.001
Con	**4.29**	0.80	111	1.25	14.35	0.003
Nat vs. Con						***0.5067***
Nat	4.06	1.30	49	1.12	7.75	0.0172
Con	4.46	1.31	37	2.58	8.55	0.0113

[1] Trt=Treatment (sand or compost bedding).

[2] SEM = Standard error on the mean. Shows the variation within the values measured.

[3] n=Total number of measures taken.

Table 2. Summary of ammonia volatilization from the surface of feedlot pens before and after box scraping during the summer months. Even though ammonia concentration appears to be lower, results showed that there was no significant difference in ammonia volatilization after scraping feedlot pen surfaces.

Trt	Mean	SEM	n	Min	Max	*P*-value
Pre	**5.4521**	0.5239	47	3.129	8.497	0.0005
Post	**4.9168**	0.5216	53	3.353	7.525	0.0008
Pre vs. Post (paired t-test)			9			0.5967

DELIVERABLE #3: DETAILED SURVEY DATA REGARDING CURRENT AMMONIA BMPS ADOPTION AND PRODUCER CONSTRAINTS TO ADOPTION

FACTORS INFLUENCING THE ADOPTION OF BEST MANAGEMENT PRACTICES FOR FEEDLOT AMMONIA EMISSIONS

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Ammonia emissions from feedlot operations pose risks to human and ecosystem health. In particular, nitrogen deposition in Colorado's Rocky Mountain National Park has been associated with livestock feeding in the western Corn Belt and Colorado. Feedlot operators can implement a variety of Best Management Practices (BMPs) to reduce ammonia emissions. These BMPs vary in simplicity, managerial time, effort and required financial capital. Although the ammonia-mitigating potential of various BMPs is well-researched, little research examines the barriers that prevent feedlot operations from adopting the BMPs. To learn more about these barriers, a questionnaire was mailed to 1,998 dairy and feedlot producers in June 2007. Survey responses (overall response rate of 7.6% for feedlots and dairies) allow determination of current levels of BMP adoption as well as producer perceptions of the environmental impact and economic feasibility of each BMP. Of the thirteen BMPs surveyed, six of the BMPs had adoption rates greater than 50%, indicating sizeable overall adoption levels. Probit analysis enables estimation of the conditional probability of adoption given a set of attributes. Explanatory variables in the probit analysis include farm characteristics as well as operator perceptions of cost, profitability, ease of adoption, and environmental impact. The results from the probit model varied substantially across BMPs, with the most robust findings for hiring a nutritionist, implementing group feeding, testing soil for nutrients and providing shade in drylot pens. Practices involving high fixed costs were more likely to be adopted by large operations and by managers that perceive a practice as profit-enhancing.

Introduction

Ammonia is produced on livestock operations when urea nitrogen in urine combines with the urease enzyme in feces and rapidly hydrolyzes to form ammonia gas (Muck, 1981). Once in gaseous form, ammonia reacts with other particles in the atmosphere, especially nitric and sulfuric acids produced from vehicles and industrial emissions to form fine particulate matter ($PM_{2.5}$). The small size of these particles enables wind to carry them from rural areas to urban areas, where they build up in the atmosphere contributing to smog and respiratory problems (Marcillac *et al*., 2007).

The U.S. Environmental Protection Agency estimates that approximately 40% of total ammonia emissions in the United States come from livestock (Battye, 1994). If livestock producers were to adopt a combination of Best Management Practices (BMPs), potential ammonia emissions reductions could approach two-thirds (Powell, 2006). Outreach professionals recognize the effectiveness and environmental trades-offs of ammonia BMPs, but have little information on producer adoption and constraints to inform their outreach strategy. Producers are likely constrained by too little investment capital, insufficient cash flows or other barriers. Barriers to adoption likely vary according to the BMP considered.

Previous research on adoption of manure management BMPs primarily focuses on practices targeted at improving water quality. A study of dairy producers (Nunez and McCann, 2008) found that off-farm income, location, perceived profitability and perceived complexity were significant factors in determining adoption of four water quality manure BMPs in Iowa and Missouri. Prior to this research, Rahelizatovo (2002) found that adoption of dairy water quality BMPs was highly influenced by farm and operator characteristics, environmental perceptions as well as producer attitudes. The current research aims to extend this body of research to ammonia BMPs, which, due to different capital, labor and technology requirements likely pose different barriers than water quality BMPs.

Materials and Methods

A survey was designed following Dillman (1991) and mailed to 1,998 feedlots and dairies in Colorado, Iowa, Kansas and Nebraska, resulting in a paltry 7.6% response rate. The survey requested information on producer adoption of thirteen BMPs listed in Table 1. These practices are known to reduce ammonia emissions (Marcillac et al., 2007) though producer knowledge of the practices' benefits may be limited. BMP adoption among the survey respondents is listed in Table 1's second column, and range from heavily adopted (e.g., using feed additives) to those that are seldom adopted (e.g., adding an acidifier to the surface of a dry lot). Each BMP was given an abbreviation that is found in the parenthesis of Table 1.

BMP adoption relies on the attitudes of feedlot managers, manager demographics, feedlot business characteristics, the local institutional environment and other factors. The hypothesized factors influencing adoption in this study are listed in Table 2 along with the manner in which they are obtained (e.g., a dichotomous variable coded as a 1 or 0) and coded for analysis. Summary statistics were tabulated, providing a general profile of the survey sample and are available from the authors upon request.

Table 1. Description and feedlot adoption rate of BMPs.

Best Management Practice	Adoption Rate
Use feed additives (ADD)	96%
Measure crude protein (PROTEIN)	93%
Practice group feeding (GROUP)	88%
Perform yearly soil test (SOIL)[1]	78%
Hire a nutritionist (NUTRITION)	77%
Collect runoff water (RUNOFF)	67%
Remove manure (CLEAN)[2]	60%
Test for nutrients (TEST)[3]	59%
Provide bedding in drylot pens (BED)	52%
Incorporate manure (INCORPORATE)[4]	42%
Provide shade in drylot pens (SHADE)	34%
Apply water to drylot surface (SURFACE)	28%
Apply an acidifier to drylot surface (ACID)	3%

[1] perform yearly soil test for cropland nutrients; [2]remove more than four times per year; [3] test manure, effluent and compost; [4] incorporate within 48 hours of application

Of the BMPs listed in Table 1, the respondents' cost perceptions of the BMP, its perceived profitability and the amount of technical expertise that is required are of particular note. These are the variables COST, PROFIT and TECHNICAL respectively in Table 2, and respondents were asked to rate their level of agreement using a Likert type scale (1= strongly disagree … 5 = strongly agree). Raw data are summarized in Table 3. As an example, measurement of crude protein (PROTEIN) is generally found to improve profitability (ranking of 4.4), requires technical assistance (4.0) and is not perceived to be costly (2.6).

The impact that Table 2's variables have on BMP adoption will vary by the practice; after all, BMP's vary in their requirements for capital, cash flow, technical expertise, etc. The general form for the relationship between the BMP and explanatory variables is listed in equation 1

(1) BMP_i = F (SIZE, CROP, STATE, INVEST, REVENUE, EDUC, DIVERSE, OWN, EXPER, FUTURE, AGE, PROFIT, TECH, COST, AIR, WATER) + e

where subscript i refers to the ith BMP in Table 1, the explanatory variables are described in Table 2, and e is the error term, which is assumed to be distributed logistically.

Table 2. Description of explanatory variables used to estimate probability of BMP adoption.

Variable	Description
SIZE	Number of cattle raised in the last year
CROP	Acres of cropland
STATE	Dummy; 0= Colorado, 1= other state
IOWA	1= Iowa
KANSAS	1= Kansas
NE	1= Nebraska
REVENUE	Cost efficiency
INVEST	Yearly investment capabilities, $
DIVERSE	Percent revenue from non-feedlot activity
OWN	Percent of cropland owned by respondent
FUTURE	Dummy; 0= invested, 1= divested
RETIRE5	Plans to retire within 5 years
LIVE5	Plans to invest in livestock within 5 years
LIVE15	Plans to invest in livestock within 15 years
EXPER	Number of years managing operation
AGE	Years
EDUC	Years of education starting from 1st grade
PROFIT	Perception of profitability of BMP
COST	Perception of cost of BMP
TECH	Perception of technical need for BMP
WATER	Perception that BMP benefits water
AIR	Perception that BMP benefits air

Table 3. Average operator response for economic perceptions of BMPs (5=strongly agree; 1=strongly disagree).

	Do you think BMP is:		
BMP	Profitable	Technical[1]	Costly
PROTEIN	4.4	4.0	2.6
NUTRITION	4.1	4.2	3.1
ADD	4.3	3.7	3.2
GROUP	4.1	2.1	2.1
SHADE	3.4	2.2	3.4
SURFACE	2.9	2.1	3.4
ACID	2.5	3.0	3.4
CLEAN	3.7	2.1	3.5
BED	3.2	1.9	3.8
RUNOFF	3.0	3.2	3.9
INCORPORATE	3.4	2.2	3.5
TEST	3.8	4.0	3.4
SOIL	4.0	4.2	3.5

[1] requires technical assistance

Discrete choice methods enabled the estimation of factors influencing the probability of adopting a BMP or set of BMPs based on attributes surveyed. Discrete choice modeling is appropriate in this research as the adoption of a BMP is coded as 1 and non-adoption is coded as 0. Probability of adoption is grounded in random utility theory, where a utility-maximizing producer chooses whether to adopt a practice (Greene, 2000; Maddala, 1983).

An initial univariate logit analysis of each of the thirteen BMP adoption equations provides preliminary estimates of the relationship between explanatory variables and adoption rates, as well as identifies candidate variables for the subsequent multivariate analysis. Variables found significant at the 25% level or greater in the univariate analysis are included in the multivariate analysis. Multivariate probit analysis is then used to improve estimate efficiency by allowing for interaction among adoption of practices. The multivariate analysis requires BMPs be grouped, and the BMPs in this study are grouped according to whether they are used in manure application (BMPs include SOIL, TEST and INCORPORATE), in managing the drylot (BED, CLEAN, RUNOFF, SHADE) or managing feed inputs (GROUP, PROTEIN, NUTRITION and ADD). Results for each group are discussed in turn.

Results

Perceptions of profitability (PROFIT) positively impact the adoption of manure application BMPs including performing a yearly soil test (SOIL), testing manure for nutrient values (TEST) and incorporating manure into cropland (INCORPORATE) within 48 hours of application (Table 4). Size of the operation (SIZE) also has positive impacts on adoption meaning that larger operations are more likely to adopt TEST and INCORPORATE, though the relative impact of SIZE is quite small compared to other statistically significant explanatory variables. Respondents who perceive SOIL and TEST to require technical expertise (TECH) are less likely to adopt the practice for that reason. The number of years managing a feedlot (EXPER) contributes to adoption of the BMP TEST. More diversified operations (DIVERSE) are more likely to incorporate manure within 48 hours of application (INCORPORATE).

Table 4. Multivariate probit results for manure application practices

Variable	Coefficient	St. Error	P-value
1. <u>SOIL</u>			
Constant	1.3589	0.3141	0.0001
SIZE	-1.55E-05	0.0001	0.6662
PROFIT***	0.4021	0.1416	0.0045
TECH***	-0.4018	0.1415	0.0045
KANSAS	-0.7727	0.5096	0.1295
IOWA**	-0.8273	0.3389	0.0146
2. <u>TEST</u>			
Constant	0.1503	0.1569	0.3381
SIZE***	0.0001	1.94E-04	0.0042
PROFIT***	0.5969	0.1864	0.0014
TECH***	-0.5959	0.1864	0.0014
EXPER**	0.0018	0.0014	0.2092
3. <u>INCORPORATE</u>			
Constant	-2.7292	0.5326	0.0001
SIZE**	-5.21E-05	1.62E-05	0.0458
PROFIT***	0.7347	0.1502	0.0001
OWN	-0.0009	0.0006	0.1288
DIVERSE***	0.0013	0.0004	0.0021
Log-likelihood			-206.58
Correlation coefficients[1]			
R(01,02)	0.3026		
R(01,03)	0.0285		
R(02,03)	0.3777		

*** significant at 1% level; **significant at 5% level; *significant at 10% level; [1] indicates correlation between BMP adoption decisions

Managing the drylot includes the BMPs of BED, CLEAN, RUNOFF, and SHADE with results presented in Table 5. Smaller operations are more likely to provide shade (SHADE) and bedding (BED). Cost efficient operations (REVENUE) are more likely to provide shade and remove manure frequently as indicated by the positive sign on SHADE and CLEAN. State location relative to Colorado influences an operator's probability of removing manure frequently- location in Iowa increases the relative likelihood while location in Kansas decreases the relative likelihood. Perceptions of profit (PROFIT) and future plans (RETIRE5, LIVE15, LIVE5) have the most significant impact on a respondents' decision to provide bedding.

Table 5. Multivariate probit results for drylot best management practices.

Variable	Coefficient	St. Error	P-value
1. BED			
Constant	-2.3091	0.4245	1E-07
SIZE*	-1.55E-05	8.46E-06	0.0676
RETIRE5**	0.0009	0.0004	0.0209
LIVE15**	-0.0007	0.0003	0.0326
LIVE5**	0.0007	0.0004	0.0396
PROFIT***	0.8464	0.1427	2.9E-07
DIVERSE	-0.0006	0.0006	0.3365
2. CLEAN			
Constant	0.5893	0.3339	0.0776
SIZE	1.53E-05	2.62E-05	0.5582
PROFIT	0.0011	0.001	0.2732
INVEST	9.07E+03	1.24E-06	0.4641
REVENUE**	0.0006	0.0003	0.0369
EDUC	0.0011	0.0007	0.1258
IOWA***	0.9296	0.2763	0.0008
KANSAS***	-0.9317	0.2698	0.0006
OWN	-0.001	0.0012	0.3947
3. RUNOFF			
Constant	-0.4467	0.2766	0.1063
SIZE***	0.0006	0.0002	0.0033
PROFIT	0.1209	0.1052	0.2502
TECH	-0.121	0.1052	0.2501
INVEST	1.74E-06	4.50E-06	0.6985
REVENUE	-0.0003	0.0003	0.3457
DIVERSE	-0.0008	0.0008	0.2853
OWN	-0.0009	0.0008	0.2194

Table 5. Multivariate probit results for drylot best management practices (continued).

4. SHADE			
Constant	0.3407	0.2679	0.2036
SIZE***	-0.0001	1.62E-05	0.0013
PROFIT	-0.0023	0.0045	0.6066
COST	0.0019	0.0045	0.6774
CROP	-0.0001	0.0001	0.2845
INVEST	7.53E-06	4.93E-06	0.1262
EXPER	0.001	0.002	0.6201
REVENUE*	0.0005	0.0003	0.0762
DIVERSE***	-0.002	0.0005	0.0001
OWN	0.0015	0.0015	0.3385
Log-likelihood	-267.21		
Correlation coefficients[1]			
R(01,02)		0.2128	
R(01,03)		0.3430	
R(02,03)		-0.3000	
R(01,04)		0.2434	
R(02,04)		-0.1551	
R(03,04)		0.0069	

*** significant at 1% level; **significant at 5% level; *significant at 10% level ; [1] indicates correlation between BMP adoption decisions

Of the four feeding BMPs, two models failed to converge (GROUP and PROTEIN), and only the amount of cropland impacts the practice of providing feed additives (ADD) (Table 6). The poor results for ADD could be explained by the lack of variability in adoption rates, as 96% of respondents use feed additives. Perceptions of cost (COST) and profitability (PROFIT) are found to statistically impact respondents' decision to hire a nutritionist. The perception that the practice is costly decreases the probability of adoption, whereas the perception that the practice is profitable increases the probability of adoption.

Table 6. Multivariate probit results for feeding best management practices.

Variable	Coefficient	St. Error	P-value
1. NUTRITION			
Constant	-1.1792	0.7229	0.1028
SIZE***	0.0008	0.0002	0.0004
PROFIT***	0.5033	0.1375	0.0003
COST*	-0.2819	0.1594	0.077
REVENUE	-0.0003	0.0004	0.3943
AIR	-0.509	0.3633	0.1612
WATER	0.5093	0.3633	0.1609
2. ADD			
Constant	1.6995	1.4406	0.2381
SIZE	0.0003	0.0007	0.7157
CROP*	-0.0001	0.0001	0.0921
PROFIT	-0.0016	0.0804	0.9838
EXPER	-0.0118	0.0343	0.7313
OWN	0.0014	0.0015	0.3421
FUTURE	-0.9359	0.9132	0.3055
REVENUE	0.0002	0.0007	0.8216
STATE	0.7564	1.26	0.5483
Log -likelihood	-60.99		
Correlation coefficient[1]			
R(01,02)	-0.6060		

*** significant at 1% level; **significant at 5% level; *significant at 10% level; [1] indicates correlation between BMP adoption decisions

Discussion

Hiring a nutritionist, collecting runoff from drylots and testing for nutrients are practices most amenable to large operations. These practices range from 59-77% adoption rates, indicating potential for increased adoption. The perception of high cost seems to limit the adoption of hiring a nutritionist, especially for small producers who are unable to distribute the high fixed cost across as many animals. A perception of technical expertise decreases the probability of testing manure and compost for nutrients, as well as for performing yearly soil tests. The technical expertise constraint particularly impacts smaller producers for testing manure and compost, while it persists across all sizes for conducting yearly soil tests.

Both providing bedding in pens (BED) and shade in drylots (SHADE) require less technical assistance than the average practice (Table 3). This result, combined with the negative relationship between adoption and size indicates they are better suited for adoption by smaller operations, as well as operations where the feedlot represents the principal revenue stream. Results indicate Colorado respondents are more likely to adopt the practice of removing manure from drylots at least four times a year as compared to respondents from Kansas. The SURFACE model did not converge in the multivariate analysis, but the univariate analysis indicated that Colorado producers are also more likely to apply water to the surface of drylots, likely due to the dry Colorado climate.

Implications

These statistical findings should be combined with professional knowledge regarding efficacy of each BMP in terms of net ammonia emissions. Removing adoption barriers implies benefits, but not every practice costs the same to implement nor generates the same ammonia reducing benefits. Thus, the benefits and costs of increasing adoption of a BMP should be considered when prioritizing research effort and BMP subsidies. It appears that outreach and policy should prioritize practices that show both promising ammonia-reduction potential and moderate adoption rates. Specific avenues for policy may include cost-sharing, encouraging size-appropriate BMP adoption and promoting BMPs found to be profitable.

DELIVERABLE #4. ON-LINE FACTSHEET SERIES AND PHOTO GALLERY ON AMMONIA BMPS.

A series of 10 factsheets have been developed or are in development for BMPs for dairies and feedlots. Factsheets in this series detail BMP options that are specific to Colorado’s Front Range, but also have more wide-ranging application. All factsheets will be published by CSU Extension and will be available on-line on the Extension website (http://www.ext.colostate.edu/pubs/pubs.html) and on the project web site (http://ammoniabmp.colostate.edu/index.html). The type of factsheets in the series and their status as of this writing are detailed in the table below. Factsheet #1: An Introduction to Ammonia can be found in Appendix A.

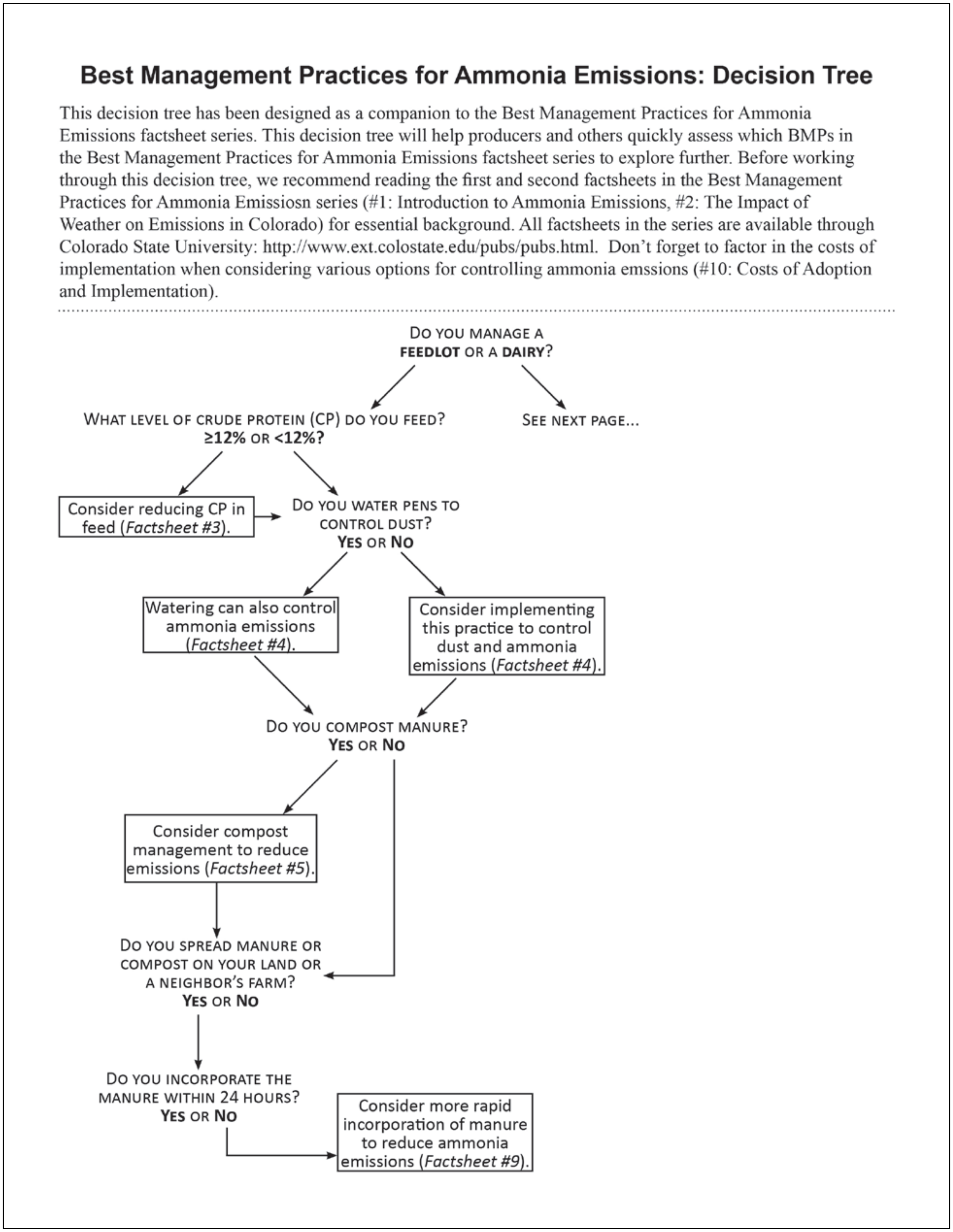
An online photo gallery on the project web site illustrates different ammonia BMPs (http://ammoniabmp.colostate.edu/link%20pages/photogallery.html).

Factsheet #	**Factsheet Title**	**Relevance**			**Status**
		Feedlot	**Dairy**	**Crops**	
1	An Introduction to Ammonia	X	X	X	Published
2	The Impact of Weather on Emissions in Colorado	X	X	X	In Preparation
3	Beef Cattle Nutrition	X			Under Review
4	Feedlot Pen Management	X			Under Review
5	Manure Composting	X	X		Under Review
6	Lagoon Covers		X		Under Review
7	Dairy Cattle Nutrition		X		Under Review
8	Dairy Bedding and Pen Management		X		In Preparation
9	Manure Application	X	X	X	Under Review
10	Costs of Adoption & Implementation	X	X	X	In Preparation

DELIVERABLE #5: DECISION TREE TO HELP PRODUCERS CHOOSE APPROPRIATE AMMONIA BMPS FOR THEIR OPERATION

A decision tree has been developed to easily guide producers and others to the BMPs that are most appropriate for them to consider implementing. This decision tree will be published as a companion to the factsheet series (Deliverable #4).

The decision tree provides a quick 1-page overview of what BMPs may be most effective in reducing ammonia emissions from specific feedlots and dairies.



Best Management Practices for Ammonia Emissions: Decision Tree

This decision tree has been designed as a companion to the Best Management Practices for Ammonia Emissions factsheet series. This decision tree will help producers and others quickly assess which BMPs in the Best Management Practices for Ammonia Emissions factsheet series to explore further. Before working through this decision tree, we recommend reading the first and second factsheets in the Best Management Practices for Ammonia Emissiosn series (#1: Introduction to Ammonia Emissions, #2: The Impact of Weather on Emissions in Colorado) for essential background. All factsheets in the series are available through Colorado State University: http://www.ext.colostate.edu/pubs/pubs.html. Don't forget to factor in the costs of implementation when considering various options for controlling ammonia emssions (#10: Costs of Adoption and Implementation).

Do you manage a **feedlot** or a **dairy**?

What level of crude protein (CP) do you feed?
≥12% or **<12%?**

See next page...

Consider reducing CP in feed (*Factsheet #3*).

Do you water pens to control dust?
Yes or **No**

Watering can also control ammonia emissions (*Factsheet #4*).

Consider implementing this practice to control dust and ammonia emissions (*Factsheet #4*).

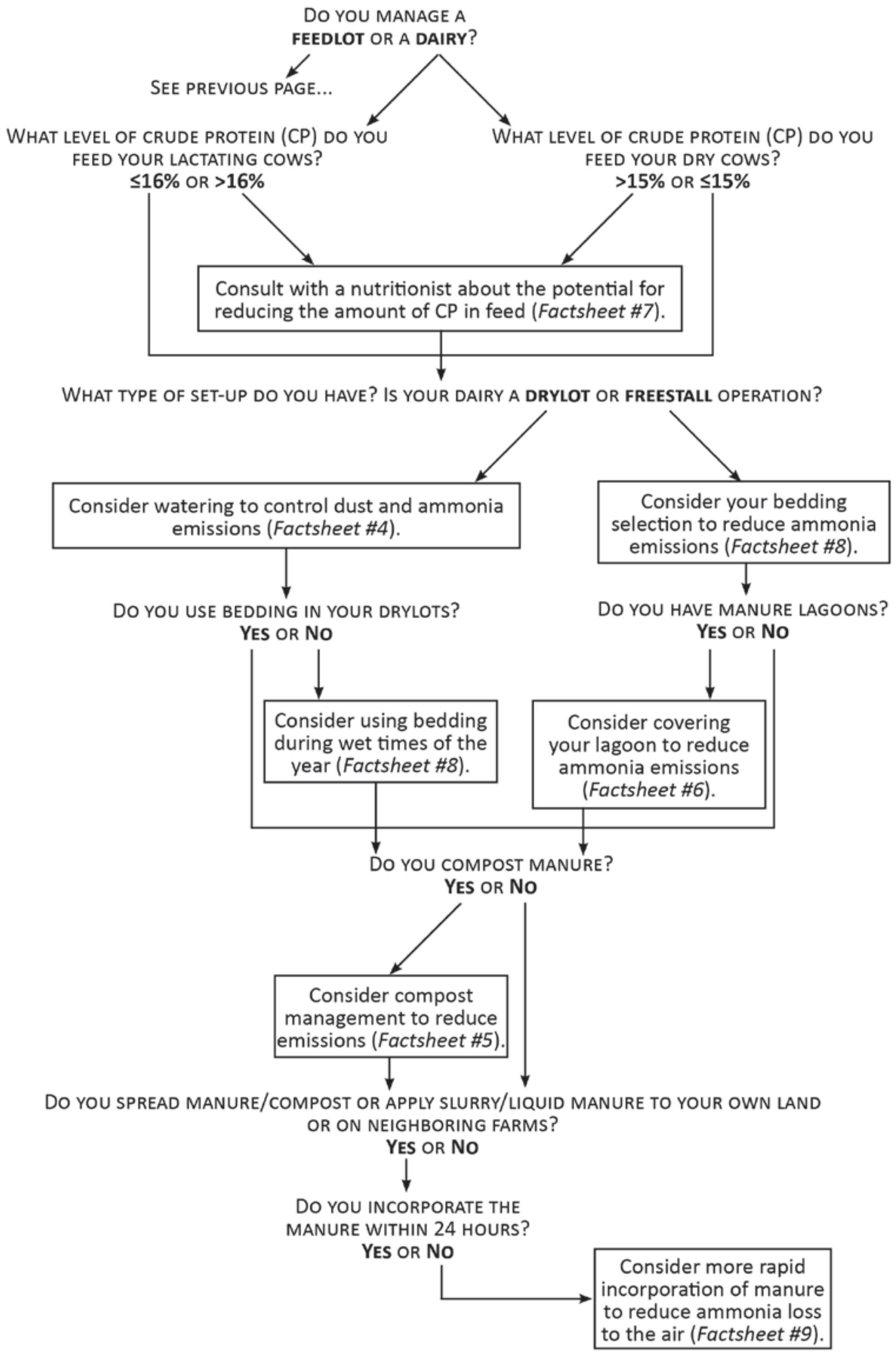
Do you compost manure?
Yes or **No**

Consider compost management to reduce emissions (*Factsheet #5*).

Do you spread manure or compost on your land or a neighbor's farm?
Yes or **No**

Do you incorporate the manure within 24 hours?
Yes or **No**

Consider more rapid incorporation of manure to reduce ammonia emissions (*Factsheet #9*).


Do you manage a **feedlot** or a **dairy**?
See previous page...
What level of crude protein (CP) do you feed your lactating cows? **≤16%** or **>16%**
What level of crude protein (CP) do you feed your dry cows? **>15%** or **≤15%**
Consult with a nutritionist about the potential for reducing the amount of CP in feed (*Factsheet #7*).
What type of set-up do you have? Is your dairy a **drylot** or **freestall** operation?
Consider watering to control dust and ammonia emissions (*Factsheet #4*).
Consider your bedding selection to reduce ammonia emissions (*Factsheet #8*).
Do you use bedding in your drylots? **Yes** or **No**
Do you have manure lagoons? **Yes** or **No**
Consider using bedding during wet times of the year (*Factsheet #8*).
Consider covering your lagoon to reduce ammonia emissions (*Factsheet #6*).
Do you compost manure? **Yes** or **No**
Consider compost management to reduce emissions (*Factsheet #5*).
Do you spread manure/compost or apply slurry/liquid manure to your own land or on neighboring farms? **Yes** or **No**
Do you incorporate the manure within 24 hours? **Yes** or **No**
Consider more rapid incorporation of manure to reduce ammonia loss to the air (*Factsheet #9*).

OTHER OUTREACH EFFORTS

In addition, we have made presentations at the:

- Colorado State University Institute for Livestock and Environment Open House,
- Colorado State University School of Global Environmental Sustainability Open House ,
- Western Section meeting of the American Society of Animal Science,
- International meeting of the American Society of Animal Science
- CIG Showcase at the international Soil and Water Conservation Society conference, and
- American Society of Agronomy.

POTENTIAL FOR TRANSFERABILITY OF RESULTS

Although all of our field demonstration took place on Colorado feedlots and dairies, we expect that the results would be applicable to neighboring states, such as Wyoming, Nebraska, Kansas, Oklahoma, New Mexico, and Utah. Beyond the region, we recommend that the BMPs be re-evaluated through on-farm testing since variation in climate and management practices could have a large impact on efficacy and affordability.

CONCLUSION

The importance of ammonia deposition in Rocky Mountain National Park has grown in the years since this project began. The literature review that we did laid an important foundation of background knowledge so that we could move forward in developing practical, affordable, and efficacious BMPs in partnership with cattlefeeders and dairy managers. Based on these findings, as well as new technologies for ammonia reduction and discussions with cattle producers, we tested the most promising BMPs on-farm to evaluate their relative effectiveness and practicality. Additionally, a detailed survey was distributed among cattle producers in CO and neighboring states to monitor current and future ammonia BMPs, with emphasis on feasibility, constraints, and cost. These demonstrations and surveys increased understanding among our stakeholders and partners regarding the constraints to BMP adoption. A series of 10 online fact sheets have been written and soon will be made available to producers along with a decision tree that will help producers choose the most appropriate technologies for their operation and budget. These tools will help cattle producers to reduce ammonia emissions and maintain environmental quality.

In the space below, provide the following in accordance with the Environmental Quality Incentives Program (EQIP) and CIG grant agreement provisions:

a. A listing of EQIP-eligible producers involved in the project, identified by name and social security number or taxpayer identification number;

Cargill Cattle Feeders, Yuma Location
Contact: Randy Van Norden, Manager
Tax ID Number: X

Aurora Organic Dairy, High Plains Location
Contact: Juan Velez, VP Farm Operations
Tax ID Number: X

Diamond D Dairy
Contact: Jim Docheff, Owner
Tax ID Number: X

La Luna Dairy
Contact: Jon Slutsky, Owner
Tax ID Number: X

Badger Creek Farms and Quail Ridge Dairy
Contact: Chris and Mary Kraft, Owners
Tax ID Number: X'

Five Rivers Feedlot, Kuner
Contact: Nolan Stone, Manager
Tax ID Number: X

Magnum Feedyard
Contact: Steve Gabel, Owner
Tax ID Number: X

Bamford Feedyard
Contact: Kent Bamford, Owner
Tax ID Number: X

Empire Dairy
Contact: Norm Dinnis, Owner
Tax ID Number: X

Lamar Feedlot, Colorado State University
Contact: John Wagner, Owner
Tax ID Number: X

b. The dollar amount of any direct or indirect payment made to each individual producer or entity for any structural, vegetative, or management practices. Both biennial and cumulative payment amounts must be submitted.

Cargill Cattle Feeders, Yuma – Purchase of Aluminum Sulfate for surface amendment BMP testing (indirect $440.00).

c. Self-certification statement

Each individual or entity receiving a direct or indirect payment for any structural, vegetative, or management practice through this grant is in compliance with the adjusted gross income (AGI) and highly-erodible lands and wetlands conservation (HEL/WC) compliance provisions of the Farm Bill.

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APPENDIX A

Best Management Practices for Ammonia Emissions
Factsheet #1: An Introduction to Ammonia

LIVESTOCK SERIES

MANAGEMENT

Best Management Practices for Reducing Ammonia Emissions

no. 1.631

by S. Lupis, N. Embertson, J. Davis [1] (11/2010)

What is Ammonia?

Ammonia (NH_3) is a chemical compound composed of one nitrogen (N) and three hydrogen (H) molecules. It is usually found in gaseous form and known for its pungent odor. Agricultural operations—cropping and livestock production—can be potential sources of ammonia, along with non-agricultural sources such as synthetic fertilizers (used on lawns, golf courses, and parks), biomass burning, plant decomposition, native soils, ocean processes, and human waste.

Ammonia is produced on livestock operations when urea (present in urine) is broken down by the enzyme urease (present in feces and soil) to form ammonia gas and carbamine acid, which further decomposes to release another molecule of ammonia gas and carbon dioxide. When urine mixes with feces or soil, ammonia is volatilized (lost to the air) within minutes, but the reaction may continue for several hours depending on a variety of factors, taking anywhere from a few hours to half a day to reach peak levels. The rate is dependent on the amount of urea and urease available for reaction as well as meteorological conditions such as temperature and wind speed.

Ammonia Transport

When in gaseous form and not blown aloft, ammonia has a short atmospheric lifetime of only a few hours and usually will deposit near its source (distance varies depending on climatic conditions) via wet deposition in rain and snow, or dry deposition. Studies have shown that the majority of gaseous ammonia gets deposited within a half mile of its source (for example, from the perimeter of a livestock operation), but some studies have shown trace amounts measured up to six miles away.

Gaseous ammonia can travel further and last longer in the atmosphere if it reacts with other chemicals and is transformed into a particle. Gaseous ammonia can react with other ambient gases and particles, including nitric and sulfuric acids (formed from NOx and SOx, respectively), contributed by industrial and vehicle combustion processes. These reactions result in the formation of solid ammoniated particles, such as ammonium nitrate and

Quick Facts...

Ammonia is produced when urea (present in urine) comes into contact with an enzyme (urease, present in feces and soil), catalyzing a chemical reaction that results in the formation of ammonia gas.

Gaseous ammonia emitted into the atmosphere can deposit quickly near the source. If ammonia is lofted high above the surface or reacts with acidic gases, its atmospheric lifetime can increase up to several weeks and can be transported more than 600 miles from the source.

Ammonia can transform into ammonium when it comes in contact with moisture and is a key component of nitrogen deposition that can impact the environment.

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ammonium sulfate, that contribute to fine particulate matter, or PM2.5, so named because it is particulate matter that is 2.5 microns in diameter or smaller. In comparison, a human hair is a whopping 60 microns in diameter! Due to its small diameter and increased atmospheric lifetime (from several days to weeks), PM2.5 may travel nearly 100 times further than gas phase ammonia before settling or falling out of the air.

Why be Concerned about Ammonia?

Ammonia gas and particulates can impact human and animal health and cause environmental degradation. If inhaled, the fine particulate (PM2.5) forms of ammonia pose a risk to human and animal health. These particles can travel deep into lung tissue and cause a variety of respiratory ailments such as bronchitis, asthma, and coughing.

In Colorado, transport and deposition of ammonia gas and ammoniated particles into pristine mountain regions, such as Rocky Mountain National Park, has been documented to result in ecosystem changes such as soil acidification, plant community changes (e.g., promoting grasses, sedges, and weedy plants while choking out native plants and wildflowers) and water eutrophication (i.e., an increase in aquatic plant production, harmful because it can lead to a lack of oxygen), which can have cascading effects throughout the entire ecosystem. In addition to ecosystem changes, ammonium, in combination with other pollutants, can contribute to smog formation and decreased visibility.

Increasingly, regulatory and policy discussions at the federal and state levels are focusing on air quality concerns from agricultural sources. In Colorado, concerns about impacts from ammonia emissions prompted the formation of the Rocky Mountain National Park Initiative, a multi-stakeholder effort to evaluate and reduce ammonia impacts to the Park. As part of that effort, a sub-group called the Rocky Mountain National Park Ag Team has been working with CSU to develop BMPs with the greatest potential for reducing ammonia emissions from agriculture.

Best Management Practices for Reducing Ammonia Emissions

Production of ammonia is an inevitable part of livestock production, but ammonia emissions can be reduced through good management. Strategies to reduce ammonia emissions from livestock production have focused primarily on preventing ammonia formation and volatilization, or downwind transport of ammonia after it is volatilized.

This fact sheet was written to provide guidance on practices appropriate in a variety of feedlot and dairy settings that have demonstrated to reduce ammonia emissions. The goal of this fact sheet is to help agricultural producers become proactive in developing practices that reduce ammonia emissions, with the hope that this will allow the livestock industry to better adapt to today's uncertain regulatory climate, as well as demonstrate leadership on the issues in a way that continues to conserve our natural resources for future generations of agriculturalists.

References and Further Reading

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