MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS

Conference Proceedings

May 19–21, 2008

Des Moines, Iowa

EDITED BY:
Ember Muhlbauer
Lara Moody
Robert Burns

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PUBLISHED BY:
Iowa State University, College of Agriculture and Life Sciences
Ames, Iowa

PRINTED BY:
Iowa State University Printing & Copy Services
Iowa State University, Ames, Iowa

COPIES CAN BE PURCHASED FROM:
Midwest Plan Services
122 Davidson Hall
Iowa State University
Ames, IA 50011
800 562-3618
Fax: 515 294-9589
www.mwps.org

ISBN 978-0-9817781-0-5

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Proceedings of the National Conference on

MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS

Exploring the advantages, limitations, and economics of mitigation technologies

May 19-21, 2008

Des Moines, Iowa

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Preface

During the last decade, increased attention has been given to odor and air emissions from animal production facilities by both the public and regulatory authorities. With this increased interest, researchers and producers have began working to identify odor and air emissions mitigation options that are both effective and economically feasible in full-scale applications. These proceedings contain the papers presented at the national conference “Mitigating Air Emission from Animal Feeding Operations: *Exploring the advantages, limitations, and economics of mitigation technologies*” held on May 19 - 21, 2008 in Des Moines, Iowa. The conference was designed to provide practical information related to mitigation of air emissions for educators and consultants working with animal production operations as well as facility owners and operators.

The proceedings are formatted as fact-sheets and are intended to serve as a practical reference on currently available air emission mitigation options. Each fact-sheet includes a technology description, details of the mitigating mechanism, applicability, limitations, costs, implementation details, and additional resources. These fact-sheets represent the opinions of the authors and the proceedings have not been peer reviewed. In addition to the fact-sheets, the proceedings also contain papers provided by the opening session keynote speakers addressing current regulatory trends and the state of the mitigation science in both the United States and Europe, as well as six papers given in special conference sessions. The proceedings are organized by mitigation technology/strategy, and both a topic and author index are included at the end of the proceedings.

These materials could not have been assembled without the participation of the fact-sheet authors who submitted information for inclusion in the conference. Their efforts provide great benefit to those working in this area, and they are greatly appreciated.

The proceedings were published through sponsorship from the Iowa State University College of Agricultural and Life Sciences and University Extension, the USDA NRI Project: *Air Quality Extension and Education: Enhanced learning Opportunities for Addressing Air Quality Issues in Animal Agriculture*, the Iowa Egg Council, the Iowa Farm Bureau, the Iowa Pork Industry Center, the Iowa Pork Producers Association, and the U.S. Pork Center of Excellence. Sincere thanks is extended to these sponsors.

On behalf of the Iowa State University Planning Committee, I hope you find the information contained here to be logically presented and that the proceedings are a practical handbook you will use as a reference for years to come.

Robert T. Burns, Ph.D., P.E.
Associate Professor
Chair, Conference Planning Committee
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Siting and Environmental Barriers

Siting Animal Production Facilities and Evaluating Odor Control Options Using the Odor Footprint Tool

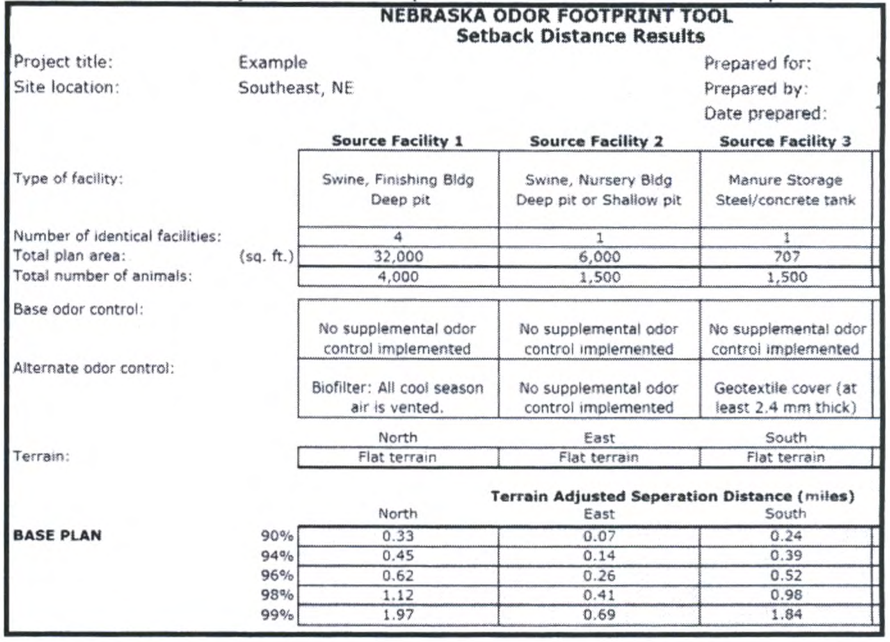
R. Stowell, C. Henry, C. Powers, and D. Schulte[1]
University of Nebraska-Lincoln[1]

Species:	Swine, Poultry, Dairy and Beef
Use Area:	Animal Housing and Manure Storage
Technology Category:	Facility Siting
Air Mitigated Pollutants:	Odor

Description:

As animal production and rural communities have changed, and the facilities in which livestock and poultry are raised have grown in size, neighbors of animal feeding operations increasingly are expressing concerns about degradation of air quality. The presumed presence of offensive odors commonly is near the top of the list of issues and complaints. Livestock and poultry producers, community planners and officials, and rural residents in general, benefit from having objective, easily visualized information upon which to make well-informed decisions regarding odor impact, siting of facilities, and odor control.

The Odor Footprint Tool (OFT) is a worksheet/spreadsheet that provides objective, science-based information on the risk-based impact of odors generated by livestock facilities. The user enters information about the livestock facilities for a given site, the site location (for selection of regional weather data), use of supplemental odor control, and any special terrain around the site. After using the Odor Footprint Tool, the user obtains minimum setback distances in four directions matching up with targets for avoiding odor annoyance (Figure 1).



NEBRASKA ODOR FOOTPRINT TOOL
Setback Distance Results

Project title: Example
Site location: Southeast, NE
Prepared for:
Prepared by:
Date prepared:

		Source Facility 1	**Source Facility 2**	**Source Facility 3**
Type of facility:		Swine, Finishing Bldg Deep pit	Swine, Nursery Bldg Deep pit or Shallow pit	Manure Storage Steel/concrete tank
Number of identical facilities:		4	1	1
Total plan area:	(sq. ft.)	32,000	6,000	707
Total number of animals:		4,000	1,500	1,500
Base odor control:		No supplemental odor control implemented	No supplemental odor control implemented	No supplemental odor control implemented
Alternate odor control:		Biofilter: All cool season air is vented.	No supplemental odor control implemented	Geotextile cover (at least 2.4 mm thick)

	North	East	South
Terrain:	Flat terrain	Flat terrain	Flat terrain

Terrain Adjusted Seperation Distance (miles)

		North	East	South
BASE PLAN	90%	0.33	0.07	0.24
	94%	0.45	0.14	0.39
	96%	0.62	0.26	0.52
	98%	1.12	0.41	0.98
	99%	1.97	0.69	1.84

Figure 1. An example of information provided and results obtained when using the Odor Footprint Tool.

Mitigation Mechanism:

The Odor Footprint Tool does not directly mitigate emissions. By using the Odor Footprint Tool, producers and their advisors can mitigate neighbor impacts of odor and air-borne pollutants through improved siting of facilities. They can also use the Odor Footprint Tool to assess the benefit of odor control technologies in terms of reduced area of odor impact, which encourages the utilization of effective control technologies.

An odor footprint is a visual picture (top view) of the risk-based odor impact of livestock facilities. Specifically, it outlines the area that is not expected to meet a selected target for avoiding odor annoyance. The minimum separation (or 'setback') distance needed from the livestock facility in a given direction is the extent of an odor footprint in that direction.

Odor footprints generated directly from dispersion modeling show the extent of risk-based odor impact in precise detail, but require specialized resources and expertise. Once baseline modeling is performed for a location, simplified footprints can be developed fairly readily for the region using commonly available resources and expertise. Simplified footprints show risk-based impact areas relative to the largest setbacks needed in one or more directions. The resulting footprints typically show fairly conservative pictures of risk-based impact areas.

The Odor Footprint Tool provides minimum separation distances to maintain in four directions around animal production facilities to meet selected risk-avoidance targets. These directional setback distances extend to the north, south, east, and west of the given facilities (Figure 2); or to the northeast, southeast, southwest and northwest. The orientation of the setback distances aligns one direction with the direction of maximum exposure to annoying odors. The science behind the separation distances comes from the use of best-available research on the rates at which farm odors are given off, move and disperse. Use of historical weather records from a representative location within a region and field validation with trained human odor assessors (Stowell et al., 2008) help make the results credible.

The Odor Footprint Tool is intended to be used as a planning and screening tool to help make timely, well-informed decisions when siting livestock facilities and evaluating odor control options. Producers, their advisors, local officials, and interested rural residents should find utility in using the Odor Footprint Tool on an informational basis. There are pros and cons of including the Odor Footprint Tool as part of local/county ordinances, and considerable thought needs to be given as to how this can be done expediently and fairly across differing types of animal production operations.

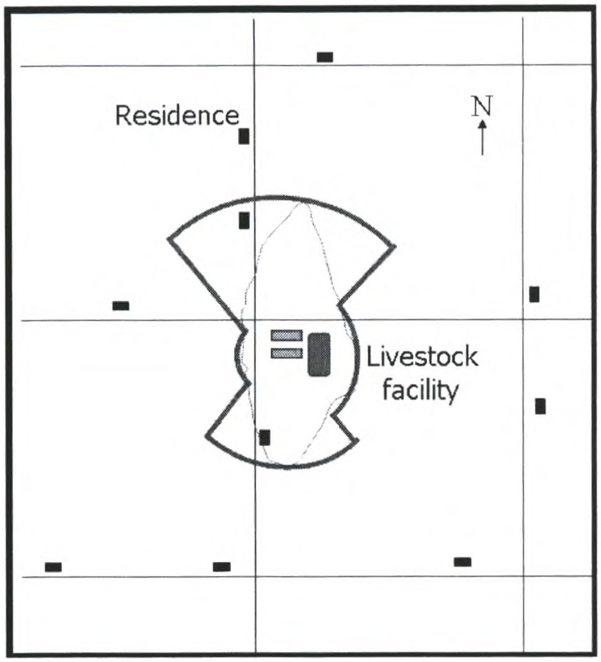


Figure 2. Odor footprints illustrate the risk-based odor impact of livestock facilities.

Applicability:

The Odor Footprint Tool applies directly to odor given off by animal production facilities. Conceptually, the results for odor have application for airborne pollutants in general, in terms of the relative shapes of footprints; but the Odor Footprint Tool is currently calibrated only for assessing odor transport (Koppolu et al., 2004).

The Odor Footprint Tool is best suited for use with housed swine, cattle and poultry. Tables 1 and 2 list the facility types for animal housing and manure storage, respectively, that accommodate use of the Odor Footprint Tool. For swine, especially, greater differentiation is made between production groups and types of facilities. The results best represent spatially concentrated animal housing and manure storage facilities.

The Odor Footprint Tool may be utilized to assess the reduction in the size of a facility's odor footprint due to use of proven odor control technology. Table 3 highlights odor control technologies that are currently incorporated into the Odor Footprint Tool. We anticipate adding to this list as independent field research verifies expected percentage reductions in odor.

The Odor Footprint Tool is designed for use on a regional basis within a state. Presently, required modeling has been performed to facilitate using the Odor Footprint Tool in Nebraska (six regions) and South Dakota (3 regions).

Table 1. Applicable animal housing facilities for use with the Odor Footprint Tool.

Species	Type/Stage of Production	Type of Facility
Cattle	Beef	Dirt/concrete lot (area is seldom dry)
	Dairy	Scraped freestall barn Slatted-floor barn over deep pit Loose housing, scraped
		Tiestall barn
Swine	Gestation	Deep-pit building
		Shallow-pit building, (e.g. pull plug system)
	Farrowing	Shallow-pit building, (e.g. pull plug system)
	Nursery	Deep or shallow pit
	Finishing	Deep-pit building
		Shallow-pit building, (e.g. pull plug system)
		Hoop barn, deep-bedded & scraped Cargill / open front, scrape
		Loose housing, scrape Open concrete lot, scrape
Poultry	Broiler	Floor-raised on litter
	Turkey	Litter

Table 2. Applicable manure storage facilities for use with the Odor Footprint Tool.

	Type of Facility
Manure storage facility	Earthen basin
	Steel or concrete tank, above or below ground
	Crusted stockpile

Limitations:

Calibrated odor emission numbers are not presently publicly available for some facilities commonly found in U.S. central plains states and other areas – such as open cattle feedlots ("dry lots") and anaerobic treatment lagoons. A reasonable amount of information is needed on both the amount of odor emitted by the facility and how odor leaves the site. In both cases, this information is less challenging to obtain from animal housing/buildings than from open, expansive surfaces that are directly influenced by the elements.

The Odor Footprint Tool presently does not account for odors that may result from land application of manure. These infrequent, but certainly not inconsequential events need to be considered for their additional odor impact.

The Odor Footprint Tool is not calibrated to use raw, unscaled emission rates or emission numbers scaled for use with another setback estimation tool (e.g. OFFSET).

Table 3. Applicable odor control technologies for use with the Odor Footprint Tool.

Odor Control Technology	
No supplemental odor control implemented on the facility	
Biofilter used to treat air from exhaust fans	Fully mechanically ventilated facility; biofilter treats 100% of exhaust air
	Mild-weather airflow is provided by fans; biofilter treats all airflow from these fans
	Biofilter treats only airflow from minimum ventilation fans
Oil sprinkling used to control dust within building	
Geotextile cover (at least 2.4 mm thick)	
Straw or natural crust on manure	2" thick
	4" thick
	6" thick
	8" thick
Impermeable cover	

Application of the Odor Footprint Tool is limited by the degree of difference in weather patterns between the site and the weather station locations. To obtain reasonably realistic odor footprints and setback information, baseline dispersion modeling needs to be performed using representative weather data (from a not-too-distant regional airport, National Weather Service station, etc.).

A major goal for the Odor Footprint Tool is that it be easy to use. To avoid the tool being too complicated, time-consuming, and expensive for practical use in the field, the Odor Footprint Tool incorporates a number of assumptions and simplifications – such as limited definition of the precise shape of the odor footprint. When application of the tool does not fit the description given in the preceding section very well, or a more precise and defensible picture of the shape of the odor footprint is required, dispersion modeling for the given specific situation is recommended.

Cost:

The primary costs associated with the Odor Footprint Tool are upfront costs of calibrating and validating the dispersion model for use with livestock odors and performing dispersion modeling using weather data for a specific area. In Nebraska and South Dakota, these costs have been largely covered by grant funds made available to the respective Land-Grant Universities.

There is no direct cost charged for using the publicly available versions of the Odor Footprint Tool to obtain directional setback distances; nor is there any charge for getting basic Extension information/assistance by phone/e-mail when using the tool. While developing plans for a new or expanded facility, a producer may work with a private consultant who uses the Odor Footprint Tool. In these situations, it is reasonable to expect to pay for consultant time associated with using the tool (< 1 hour involved in most cases), getting their technical response and recommendations, creating project-specific visuals (e.g. illustrating directional setbacks on aerial photograph or plat map), and presenting material to permitting authorities, local zoning commissions, lenders, etc.

Some operations may want a more precise and technically defensible odor impact assessment – such as an operation seeking information to bolster its position concerning the expected level of odor impact of proposed new facilities or defending itself against a lawsuit concerning existing facilities. A preliminary estimate of baseline private consulting charges associated with performing and supporting site-specific dispersion modeling is $15,000-30,000 per site. While such information and service has its place and value, going beyond using the relatively simple Odor Footprint Tool for planning and screening purposes probably cannot be justified economically for most common scenarios and herd/flock sizes.

Implementation:

To directly use the Odor Footprint Tool, a prospective user needs to access the worksheet or spreadsheet version of the OFT and follow instructions provided in the associated user's manual. On-line access to the Nebraska's OFT resources is now available via <www.manure.unl.edu>, within the Odor and Air Quality section. As an alternative to learning to use the Odor Footprint Tool, producers may contact Extension or work through a consultant/advisor.

Use of the Odor Footprint Tool is usually of greatest benefit when used early in the planning process. Therefore, we advocate that producer advisors and consultants be aware of the Odor Footprint Tool and, ideally, be trained to use the OFT. Training workshops conducted by University of Nebraska Extension are available for individuals who are likely to use the Odor Footprint Tool in regular interactions with producers. Training involves a commitment of 3-4 hours of contact time.

Regardless of who actually navigates the Odor Footprint Tool, information must be available on the:

- Proposed site location and what region(s) may be most representative of this location climate-wise;
- Type of facility(ies) to be built on the site;
- Basic dimensions of the facility(ies);
- Type of odor control being considered, if any;
- Desired or required annoyance-free frequency(ies) to be maintained; and
- The terrain surrounding the facility.

Technology Summary:

The Odor Footprint Tool is a worksheet/spreadsheet that provides objective, science-based information on the risk-based impact of odors generated by livestock facilities. The user enters information about the livestock facilities for a given site, the site location (for selection of regional weather data), use of supplemental odor control, and any special terrain around the site. After using the Odor Footprint Tool, the user obtains minimum setback distances in four directions matching up with targets for avoiding odor annoyance. The Odor Footprint Tool can help assess the reduction in the size of a facility's odor footprint due to use of proven odor control technology.

The Odor Footprint Tool is currently suited for assessing the risk-based odor impact of housed swine, cattle and poultry, as well as spatially concentrated manure storage facilities. The Odor Footprint Tool is not currently well-suited for use with large, open area sources (open lots, lagoons) or land application.

The Odor Footprint Tool is designed for use on a regional basis within a state where baseline dispersion modeling has been performed. Application of Odor Footprint Tool results in other areas will be limited by differences in regional weather patterns.

There is no direct cost charged for using the publicly available versions of the Odor Footprint Tool to obtain directional setback distances. The primary costs associated with the Odor Footprint Tool are upfront costs of calibrating and validating the dispersion model and performing dispersion modeling using weather data for a specific area.

Additional Resources:

The worksheet and spreadsheet versions of the Odor Footprint Tool are available at <www.manure.unl.edu>, within the Odor and Air Quality section, along with the following related resources.

Understanding Odor Footprints and the Odor Footprint Tool (FAQs)
Odor Footprints and the Odor Footprint Tool: An Overview
Determining Separation Distances Using the Odor Footprint Tool: User's Manual for the Worksheet-Based Tool
Determining Separation Distances Using the Odor Footprint Tool: User's Manual for the Spreadsheet Tool

Acknowledgments:

Funds to support research, development and/or demonstration of the Odor Footprint Tool were provided by:

Nebraska Department of Agriculture
USDA CSREES National Research Initiative
Nebraska Environmental Trust
Nebraska Pork Producers Association / NPB
South Dakota Pork Producers Association

References:

Koppolu, L., D. Schmidt, D. D. Schulte, and L. Jacobson. 2004. Development of scaling factors (peak-to-mean ratios) through dispersion modeling with AERMOD and field-based odor measurements for livestock facilities. ASAE paper # 044196. ASAE, St. Joseph, MI.

Stowell, R. R., K. R. Niemeir, and D. D. Schulte. 2008. Validating the Odor Footprint Tool Using Field Data. 2008 Nebraska Swine Report, EC 219, p. 39-41 Institute of Agriculture and Natural Resources, University of Nebraska - Lincoln.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
Iowa Farm Bureau Federation
Iowa Egg Council
Iowa Pork Industry Center
Iowa Pork Producers Association
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Siting of Livestock and Poultry Facilities Using MNSET

D. Schmidt and L. Jacobson
University of Minnesota

Species: Swine, Beef, Dairy Poultry
Use Area: Animal Housing and Manure Storage
Technology Category: Facility Siting
Air Mitigated Pollutants: Odor, Hydrogen Sulfide, Ammonia

Description:

The Minnesota Setback Evaluation Tool (MNSET) is a prediction tool that can be used for quickly evaluating odor, hydrogen sulfide, and ammonia impacts from a feedlot. MNSET combines the original odor impacts predicted using OFFSET with additional dispersion modeling results for hydrogen sulfide and ammonia based on AERMOD, an EPA approved air dispersion model. This original modeling effort began in 2003 with a field validation and calibration of AERMOD on a farm in Iowa (Schmidt et al, 2004). This same model was then used to predict hourly downwind concentrations of hydrogen sulfide from twenty-one case studies (Schmidt et al., 2006). Case farm model inputs included source layout and dimensions, hydrogen sulfide flux rates, along with five consecutive years of historical weather data, 1986 through 1990, at four geographic locations including Minneapolis, Minnesota, Rochester, Minnesota, Fargo, North Dakota, and Sioux Falls, South Dakota. From these results, a statistical model was developed to evaluate downwind concentrations of hydrogen sulfide and the probability that these concentrations would exceed the Minnesota ambient air quality standard for hydrogen sulfide.

MNSET input parameters include source dimensions, flux rates of odor, hydrogen sulfide, and ammonia for the source, the presence of any mitigation technologies and the efficiencies of these technologies. It should be noted that as with any dispersion model, the emission rate (mass of pollutant emitted over time) is the most significant variable affecting downwind concentrations and that these downwind concentrations are linearly related to a specific site emission rate which is in turn related to the size of the emitting source and its flux rate. For instance, at a given receptor location, a 50% reduction in site emissions would result in a 50% reduction in concentration at this receptor.

MNSET estimates three separate outputs. The first estimation is for the frequency of downwind odor impacts. These outputs are based on the original OFFSET work done by Jacobson et al. (2005) and reported by Guo et al. (2005). As in the original OFFSET model, there are no provisions for predominant or prevailing wind direction (setback distances predicted based on direction from the site). The general belief held by the model developers is that worst case odor events occur under relatively low wind conditions and that the directional component of these low wind conditions is not easily determined and hence is not included in any data set of historical weather. As such, the inclusion of wind direction could result in under predicting the frequency of odor events. Figure 1 shows the estimated odor impacts from a 3000 head swine finishing facility in Minnesota.

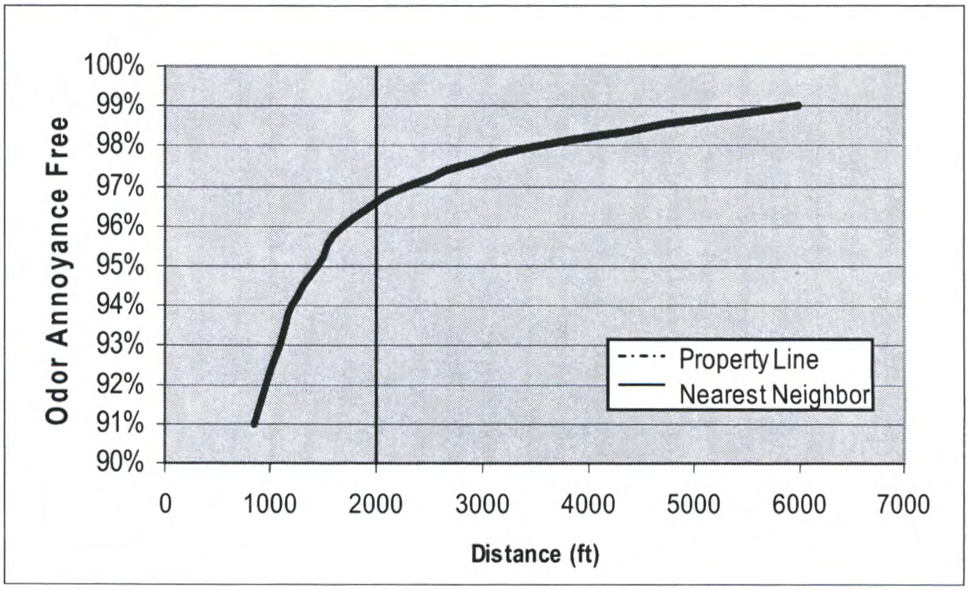

Figure 1. MNSET predicted odor impacts from 3000-head swine finishing building. Nearest neighbor and property line distances are also noted.

MNSET also predicts the expected frequency of exceeding the Minnesota Standard for ambient hydrogen sulfide concentration at a specified distance, typically, the nearest property line. As would be expected, these exceedences occur more frequently near the farm and less frequently at distances further from the emission sources (figure 2). Note how quickly the exceedence frequency drops over the first 500-700 feet from the source. This probability curve looks very similar for most sizes of farm sites suggesting that setbacks greater than 1000 feet would likely meet MN state regulatory standards for hydrogen sulfide.

Additionally, MNSET also predicts the daily pollutant load for hydrogen sulfide and ammonia. For the example of the 3000 head swine finishing barn MNSET predicts 3 lbs per day of hydrogen sulfide emissions and 42 lbs per day of ammonia emissions. All MNSET are based on average values for flux rates found in literature. It is likely that future research will better document these flux rates thus improving the model predictions.

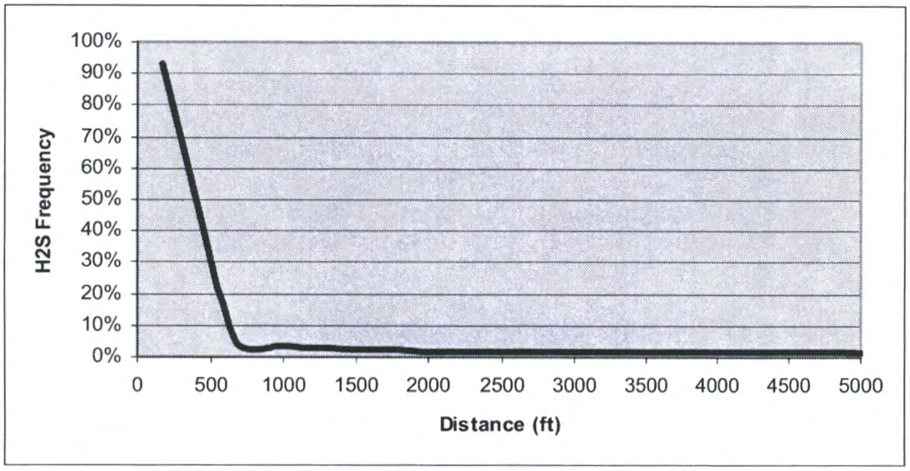

Figure 2. Predicted frequency of exceeding the Minnesota ambient hydrogen sulfide standard.

Mitigation Mechanism:

MNSET can be used in the siting of new facilities and determining the impacts of mitigation techniques on new or existing facilities.

New Facilities

Siting of new livestock facilities is often met with opposition related to ambient air quality issues related to odor nuisance or human health. This opposition is not always based on sound science. However, defending the siting location is not always based on sound science either. Site specific dispersion modeling is sometimes done but this can be both expensive and time consuming. MNSET is a viable alternative to site assessment that can be done at little or no cost and completed in a short amount of time.

Simple inputs of types and sizes of buildings, lots, and manure storages into MNSET will result in predicted frequencies of odor impacts at distances from the proposed site. Additions of mitigation technologies to the site will quickly show changes in these odor impacts. This predicted information allows for a more objective discussion about odor nuisance issues. Using these same inputs, MNSET also predicts the frequency of exceeding Minnesota ambient air quality standards for hydrogen sulfide, a gas associated with both nuisance issues and human health concerns. In areas where local concerns are related to nitrogen loading, MNSET can be used to predict annual loading from the proposed site (and reductions of load based on implementation of mitigation techniques.) For instance, model results shown in Figure 1 for a 3000 head swine finishing facility suggest that the proposed location, 2000 feet from the nearest neighbor, will likely result in annoying odor problems approximately 3.5% of the time (96.5% annoying odor free). By moving the site location the neighbor impact could be reduced or increased according to the curve shown. In addition, it is easy to assess the downwind impacts of any

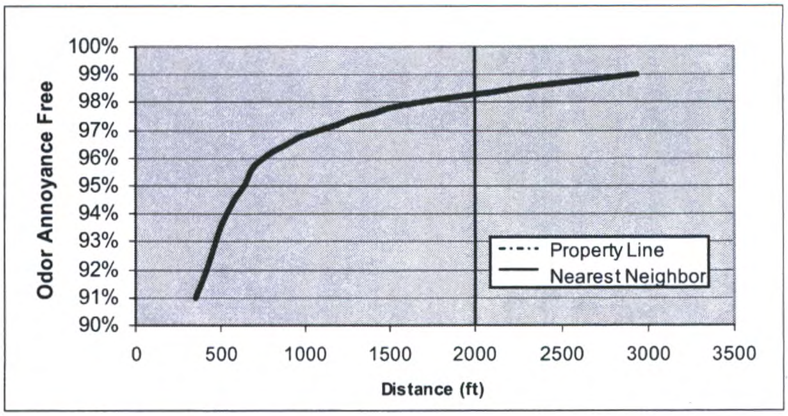

Figure 3. Example output for a 3000-head finishing barn with 75% odor mitigation technology implemented.

proposed mitigation techniques. MNSET has built in drop down boxes for several mitigation technologies and allows for additions of other technologies currently not listed in the program. Figure 3 shows the predicted odor impact with the addition of a technology that reduces the site emissions by 75%. With this scenario, MNSET estimates indicate a decrease in odor impacts to the level of less than 2% of the time.

Existing Sites

MNSET can also be used to evaluate the use of mitigation technologies to solve existing siting issues. Production sites with existing neighbor complaints, or regulatory compliance issues related to air quality, are often willing to implement mitigation technologies if there is 1) some indication that the nuisance or regulatory issue actually exists and 2) if the proposed mitigation technique is likely to resolve this nuisance or regulatory issue. The question might be, "If I implement technology 'X' that provides an estimated 20% reduction in emissions, will this be enough to solve my problem or do I have to implement technology 'Y', a much more expensive technology but reduces emissions by 80%." Site specific dispersion modeling can assess this situation but this situation can also be effectively evaluated with MNSET. Within seconds these technologies options can be assessed for both neighbor and property line impacts. Additionally regulatory compliance issues related to annual pollutant load can also be estimated. Currently, MNSET results are not accepted by regulatory agencies however, efforts are being made to show that MNSET results are likely more restrictive than accepted regulatory models which will enhance the use of MNSET a screening tool for these issues.

Implementation and Applicability:

Although MNSET was developed specifically for use with Minnesota building types and weather conditions, the model can be used to predict relative impacts from different types of facilities in any geographic location. Flux data (mass/area/time such as grams/second/square meter) from buildings and area sources used in the model are based on the best literature values at the time of model development. These values are not specific to Minnesota and there is little data to show how these values might change geographically across the US or other parts of the world. As such, the default values for the given sources are likely applicable in most situations. However, not all types of emission sources are listed in the model. There are new styles of barns or obscure emission sources (e.g. dead animal composting piles) where no flux data is available. Knowing that this is an issue, MNSET incorporates a feature to allow the user to enter other source types and corresponding flux data as it becomes available. This is also true for mitigation technologies. There are some mitigation technologies listed in the model but the model allows for users to include additional mitigation technologies and corresponding reductions. One caution however, is the need for documenting flux data or mitigation efficiencies for any of the user inputs into the model. For instance there are several mitigation technologies that claim significant reductions and the user would be wise to verify these claims prior to including these reductions in the model results. MNSET allows for this type of documentation.

MNSET predictions for ambient impacts are based on historical Minnesota meteorological data. As such, applying this model for downwind impacts in other geographic regions currently requires some programming changes to the model. These changes have been done for several states for the original version of OFFSET and involve determining frequencies of wind speed and stability classes for these areas. Without this information, MNSET results for downwind impacts are only reliable in Minnesota. However, other geographic regions can still use MNSET for site comparisons and "what if" scenarios. Downwind impacts for neighboring states will likely be very similar to what is predicted for Minnesota.

Cost:

MNSET is an EXCEL spreadsheet model and is available free on-line at www.manure.umn.edu then click on "Air Quality." The use of MNSET to quickly evaluate and compare the impacts of various technologies will also save time and money on siting decisions and decisions related to choosing the appropriate mitigation technology.

Technology Summary:

MNSET predicts three separate values. The first prediction is for odor impacts at any given distance downwind from the facilities. The second prediction is for the frequency of exceeding the MN state standard for hydrogen sulfide. Although this may not be applicable for other states it does show relative impacts of hydrogen sulfide. Additionally, MNSET estimates both daily and annual pounds of hydrogen sulfide and ammonia emitted from the modeled facility. Remember however that the outputs of the models are only as valid as the inputs. A literature review was done to develop the flux values used in the model.

Additional Resources:

Please visit www.manure.umn.edu for more information on MNSET.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
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Pennsylvania's Odor Siting Index

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Species: Swine, Poultry, Dairy, Beef feedlot, Veal
Use Area: Animal Housing and Manure Storage
Technology Category: Facility Siting & Management
Air Mitigated Pollutants: Odors

Description:

The Pennsylvania Siting Index was developed in response to specific state legislation (PA Act 38 of 2005) in an effort to objectively evaluate locations for new or expanding regulated animal operations, then develop an Odor Management Plan to reduce the potential for community conflict from building and manure storage odors. The goal is to construct livestock operations where community odor conflict potential is minimized. Data from the site and site map are entered into the index and the resulting score indicates the complexity of Best Management Practices (BMPs) that must be adopted for a producer to develop the site. Scores of less than 50 index points do not require any BMPs. Scores from 50 to 99.9 index points require "Level 1" BMPs, which are generally standard, industry-accepted practices. Scores greater than 100 points require more costly and complicated "Level 2" BMPs. The index cannot be used to stop a proposed operation, nor is it used to mitigate specific air emissions.

Mitigation Mechanism:

The Odor Siting Index

The index evaluates odor generation potential, location of potential odor receptors, and designated land use, with a goal of encouraging producers to locate new or expanded facilities in locations where odor conflict will be minimized. If the index score indicates the proposed operation has a high probability of causing community odor conflict, the producer must implement one or more BMPs to either reduce odor generation at the site or reduce odor transfer from the site to the receptors. Alternately, the producer may choose a different location with a lower index score.

To begin indexing a site, an evaluation distance is established depending on the number of AEUs (Animal Equivalent Unit, 454 kg (1000 pounds) of animal body weight on an annualized basis) proposed. Evaluation distances for AEU categories are as follows:

<50 AEUs	366 m (1200 ft)
50-199 AEUs	549 m (1800 ft)
200-599 AEUs	732 m (2400 ft)
>600 AEUs	914 m (3000 ft)

A map of the site identifies the operation footprint, property lines, and location of all potential receptors (homes, businesses, etc.), and other animal operations within the evaluation distance. From the geographical center of the operation footprint, the surrounding area is divided into four 90-degree directional quadrants (North, South, East, and West) at 45, 115, 225, and 315 degrees from due North to establish the direction of receptors from the odor source. In addition, circles are drawn at 366 m (600 ft) intervals to the maximum evaluation distance for the site so that each receptor is located in a distance/direction subset. Based on the legislative language, the following factors were selected for inclusion in the index score.

1. Odor Source Factors (range of 14 to 47 index points):
    - Facility size (AEUs) of the regulated operation (range of 2 to 10 points)
    - History of livestock on the site (range of 0 to 12 points)
    - Species or type of livestock (range of 10 to 15 points)
    - Manure storage type (range of 2 to 10 points)

2. Site Land Use Factors (potential for 0 to 35 points deducted from the index score):
    - Is the land located in township's Agricultural Security Area? (5-point deduction)
    - Is the land zoned for agricultural production? (10-point deduction)
    - Has the land been permanently preserved for agricultural production? (20-point deduction)

3. Surrounding Land Use Factors (potential index points range from -5 to an unlimited value):
   Other livestock (>8 AEUs) within the evaluation distance (range of -5 to 5 points)
   Distance from nearest corner or edge of footprint to property line (range of 0 to 10 points)
   *Number of non-public receptors (homes) within each distance/direction subset (range from 0 to unlimited points)
   *Number and location of public use facilities (limited to public schools, hospitals, elder care homes, and buildings with >4 living units) within each distance/direction subset (range from 0 to unlimited points)

*Points assigned for these factors are adjusted for distance/direction subset (nearby receptors to the east and south are assessed more index points), and intervening topography and vegetation (index points for receptors shielded by topography or vegetation are adjusted downward).

Index scores of 27 existing and proposed swine, poultry, and dairy farms were calculated in a pilot exercise and ranged from -2 to 246 index points. Twenty of the 27 farms scored fewer than 50 index points. Five farms scored between 50 and 99.9 index points, and two farms scored more than 100 index points.

Best Management Practices

Best Management Practices are described in two levels (Level I and Level II) based on expense and ease of implementation. Level I BMPs are proscribed based on species and production system. For example, Level I BMPs for confined poultry operations would include:

- Cake out litter and till litter between flocks (floor birds only)
- Monitor water lines and drinkers for leaks
- Monitor for egg jams (layers only)
- High pressure wash or dry clean between flocks
- Minimize feed wastage
- Phase feed

If a site scores more than 100 index points, the planner, producer, and State Conservation Commission must agree on one or more appropriate Level II BMPs to address the major odor source. Potential Level II BMPs include:

- Aeration of manure storage
- Air scrubbers
- Anaerobic digestion
- Biofiltration
- Composting manure
- Special feed formulation
- Covering manure storages
- Manure pit additives
- Oil sprinkling
- Wind barriers, shelter belts

Regulations allow for BMP lists to be adjusted and updated as technology and efficacy data become available.

Odor Management Plan

After the site has been indexed and BMPs selected (if required), an odor management plan must be developed and submitted to the Pennsylvania State Conservation Commission for approval. The plan must follow an approved format and contain the following sections:

1. Plan Summary Information
   a. Operator Commitments and Responsibilities
   b. Farm Identification
   c. Operational Map Information
2. Plan Evaluation Information
   a. Odor Site Index
3. Odor BMP Information
   a. BMP Implementation, Operation & Maintenance Schedule
   b. BMP Documentation

Applicability:

In Pennsylvania, the index and associated Odor Management Plan (OMP) will be required for new or expanding operations that fall under the state's nutrient management regulations (>2000 pounds of annualized animals per acre of manure application area, Concentrated Animal Operation), or federal CAFO regulations. All applicable species and production systems are included. Non-regulated operations may develop an index score and OMP and receive limited liability protection from nuisance odor complaints.

Limitations:

1. The index does not attempt to quantify odors or specific gasses, nor does it objectively measure the effectiveness of BMPs.

2. Assumptions made regarding index scores based on species and adjustments for shielding by topography and vegetations are based on limited data.

3. The potential for conflicts due to inversion odors is ignored in the index because of the difficulty in consistently predicting which neighbors would be affected.

4. Regulations indicate that a site must only be scored and a plan developed once unless the operation is substantially changed. Thus, encroaching development could create conflict where none existed at the time of construction.

5. The index value increases with an increasing number of homes within the evaluation distance. There may be circumstances in which the total number of homes is low, but those that exist are relatively close to the operation. The resulting index score in such an instance could be fewer than 50 points, which would require no BMPs.

Cost:

Because the regulations are not yet finalized, no official plans have been developed to date. The Pennsylvania State Conservation Commission estimates the cost to producers for developing an index and associated odor management plan will be approximately $1120 (16 hrs * $70/hr). BMP installation and maintenance costs would be variable, depending on BMP complexity. If producers choose a site with an index score of <50 points, BMPs would not be required thus erasing all BMP costs.

Implementation:

Producers are required to obtain an approved odor management plan and written approval from the Pennsylvania State Conservation Commission prior to populating the regulated building or using the regulated manure storage structure. Producers are required to implement and document required BMPs according to the approved odor management plan's schedule and are subject to annual inspection by the State Conservation Commission. Implementation, operation and maintenance records will be reviewed during inspections.

Technology Summary:

Pennsylvania's odor siting index is designed to urge producers to locate operations in locations where potential for community odor conflict is minimized. If producers choose to build animal facilities on a site with a high odor index score, state legislation requires implementation of BMPs to reduce odor generation and/or dispersion. An odor index and odor management plan are both required for operations regulated by state nutrient management laws (animal density-driven), or federal CAFO laws.

Additional Resources:

Pennsylvania's Odor Management Program:
http://www.agriculture.state.pa.us/agriculture/cwp/view.asp?a=3&Q=145162&PM=1

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
Iowa Farm Bureau Federation
Iowa Egg Council
Iowa Pork Industry Center
Iowa Pork Producers Association
U.S. Pork Center of Excellence

A Receptor-Based Siting Strategy for Swine Production Systems

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Species:	Swine
Use Area:	Animal Housing, Manure Storage
Technology Category:	Facility Siting
Air Mitigated Pollutants:	Odor

Description:

A model, called the Community Assessment Model for Odor Dispersion (CAM), was developed to predict receptor odor exposure from multiple swine production sources. The intended use of CAM was to provide a tool for evaluating the odor exposure to receptors in a community when siting new swine production systems and how a change in odor control technology alters the odor exposure to receptors. CAM can handle up to 20 swine production sources with up to 100 receptors in a community of any size. The model incorporates historical (10+ years) average local weather data, coordinate locations of all sources and receptors, ground and above-ground area sources, seasonal variations in odor emission, source production footprint and orientation, and documented proven odor mitigation technologies. CAM does not predict the influence of calm conditions, topography, or obstruction downwash. CAM predicts the number of hours of exposure to weak (2:1) and greater or identifiable (7:1) and greater odors and these are used to assess siting options.

Current siting requirements for new livestock and poultry production systems in the U.S. are based mainly on animal units and distance to the nearest neighbor independent of direction (eg. Iowa DNR, 2005; Missouri DNR, 2006). Separation distance alone does not account for existing odor sources in a community, nor the influence of localized weather patterns on odor dispersion. An alternative approach would be to develop a receptor-based procedure for making decisions on where a swine facility of a given size could be placed in a community with or without a pre-existing odor load. In this manner, siting decisions could be made using historical weather patterns, size of production facility, odor mitigation measures implemented, and existing odor loads in a community.

The objective of this paper was to summarize an organized procedure for assessing odor exposure to individual receptors in localized areas of a community. The goal was to develop a procedure that could fairly and accurately describe the long-term historical exposure of odor emission from multiple swine barn ventilation air and manure area sources to multiple receptors in a community of any size. Historical average meteorological conditions in localized areas along with odor emission parameters that describe barn ventilation air and manure area odor sources were implemented in an attempt to provide a siting tool that predicts historical average expectations as opposed to hourly or daily observations.

Mitigation Mechanism:

The mitigation mechanism described with this paper is related to pre-planning siting efforts when considering new or expanding swine production systems. In terms of new construction, proper siting is a very effective odor mitigation strategy. Proper siting can alleviate in many cases the need for odor mitigation.

Modeling odor dispersion by itself is a relatively straight-forward procedure. The difficulty arises when a modeling procedure is to be used by farmers and community planners to guide facility siting choices. Any modeling procedure developed must be based on an accepted modeling platform, must incorporate site parameters that can be applied equitably to a wide range of field conditions, must have the ability to easily handle multiple sources and multiple receptors, and must predict odor concentration that is conservative for the receptor without being overly restrictive for the farmer. Any odor dispersion model that incorporates these considerations and shows good agreement with field collected odor data could be considered for siting purposes.

Applicability:

This paper discusses a technique that has been developed for swine housing and outside manure storage facilities. The current procedure is limited to swine. CAM can evaluate up to 20 swine-related sources and up to 100 receptors in a land area of any size provided local historical (10+ year average) weather data exists.

Limitations:

The modeling procedure described in this paper requires localized historical weather data, does not consider calm conditions, and can not model terrain features beyond rural agricultural terrains.

Cost:

The CAM model requires site specific information to properly implement. Currently CAM is implemented with the ½-time support of an on-campus staff member with no charge to the farmer. A more formal procedure is being developed where a CAM evaluation will require a farmer-fee of either \$500/siting case or \$1,000/siting case depending on the complexity of the proposed site. A \$500 cost to a farmer would be a situation where a campus or extension field staff member is required to visit a proposed site to help guide siting decisions using localized odor plots (described in next section). If the complexity of the proposed site warrants a full CAM modeling run, an additional \$500 is required from the farmer.

Implementation:

CAM has been used in the state of Iowa for over 150 specific cases since June 2005. The implementation of CAM has been a voluntary process, initiated by the farmer and implemented through a joint effort between the Coalition to Support Iowa's Farmers (CSIF, 2008), the Iowa Pork Industry Center (IPIC, 2008), and faculty with Iowa State University's College of Agriculture and Life Sciences. A farmer proposing a new site first contacts the CSIF. An initial assessment is made of the site based on aerial and platt maps followed by a site visit. In many cases, the CSIF site visit is sufficient to assess the proposed site. If the proposed site requires a CAM modeling run, a staff member from IPIC conducts a follow-up site visit and using aerial maps, platt maps, and on-site observations, grids the community identifying all potential receptors and existing emission sources. Special indicators are given for receptors to identify sensitive areas such as churches, cemeteries, and day cares. The mapped data is then brought to Iowa State Universities Department of Agricultural and Biosystems Engineering where one of two faculty members implements CAM. A one-page report is generated and this report is given to the farmer, through a follow-up on-site visit with an IPIC staff member.

Local weather data is incorporated with an historical 16-point wind rose, average monthly wind speed (WS), average monthly outside temperature (T), and average monthly solar radiation (SO). Monthly data from March through October is used in CAM. Monthly averaged T is used to estimate housing ventilation rate and seasonal odor concentration. Monthly averaged WS is used to estimate odor emission from above-ground and ground-level area sources. Monthly averaged WS and SO data is used to estimate daytime atmospheric stability.

The 16-point wind direction (WD) data is used to estimate the total number of hours that a receptor might be subjected to downwind events. The assumption is made that the 22.5° increment of WD data surrounding each 16-point compass direction (±11.25°) has an equal chance of occurring. A source-to-receptor (S-R) exposure angle is determined based on the equivalent diameter defining the source (area or building or both combined) and the distance from the source center to receptor. Of the total S-R hours, the fraction of nighttime to daytime hours (varied by month) is used to further discretize these hours. This procedure is used to determine the maximum number of hours that a receptor could be subjected to an odor based solely on WD. Of these total "WD" hours, the actual number of hours exposed to an odor of a given concentration is determined using CAM procedures and the average monthly weather data. The actual odor exposure hours will in most all cases be significantly less than the WD hours, depending primarily on separation distance and average monthly WS.

The practical use of CAM is presented for a multiple source-multiple receptor situation modeled in central Iowa. A 2,400-head deep-pit swine finisher (DPSF) was being planned for construction in central Iowa at the location shown in figure 1. The proposed source (PS) location met all distance requirements established in Iowa at the time of siting (Iowa DNR, 2005) where a minimum required distance to the closest receptor (unincorporated areas) is 381 m (1,250 ft). The nearest receptor to PS was R10 (figure 1) at a distance of 647 m (2,122 ft). Also present in this community were three pre-existing DPSF facilities labeled as S1, S2, and S3. In total, this community consisted of 20 potential receptors, three existing DPSF sources, and the proposed DPSF source.

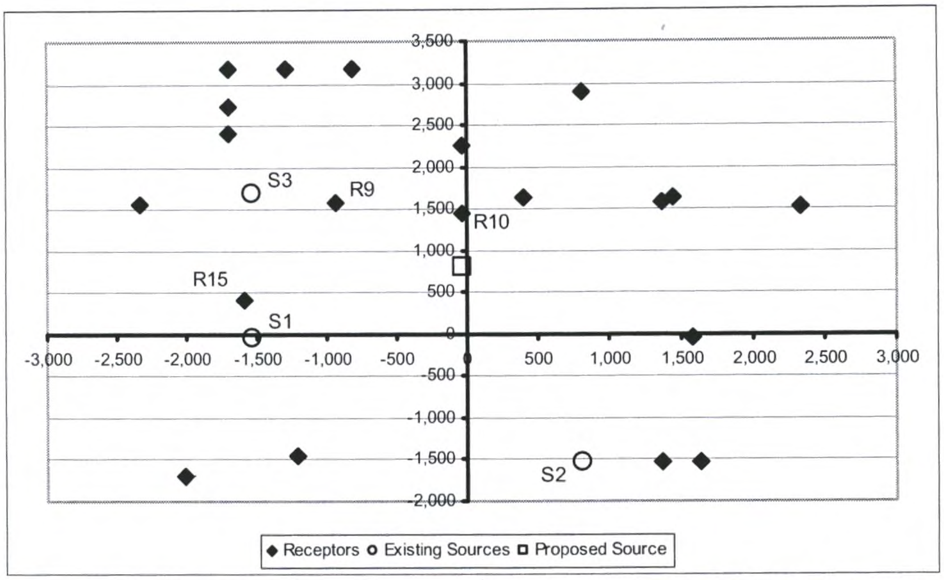


Figure 1. Case study community situation modeled. The community consists of 20 receptors (♦), 3 existing swine sources (○) along with the proposed source (□). Dimensions in meters.

The estimated odor emission data along with monthly variations in wind direction, wind speed, solar insulation, and daytime/nighttime hours for central Iowa were incorporated into CAM resulting in the receptor odor exposure predictions given in table 1 (3/20 receptor results given).

Table 1. Predicted number of hours of exposure to weak (≥2:1) and identifiable (≥7:1) odors for receptors 9, 10, and 15 (see figure 1).

Receptor	OU/m^3	PS Hrs.	S1 Hrs.	S2 Hrs.	S3 Hrs.	Total Hrs.	PS % Time	Total % Time
R9	2:1	22	16	4	64	106	0.4	1.8
	7:1	15	8	0	37	60	0.3	**1.0**
R10	2:1	50	7	5	14	76	0.9	1.3
	7:1	38	4	0	5	47	**0.6**	0.8
R15	2:1	9	194	4	18	225	0.2	**3.8**
	7:1	4	78	0	15	97	0.1	**1.6**

From the data presented in table 1, along with odor-limit criteria, an assessment could be made regarding this siting choice. For the test cases conducted in Iowa (150+ since 2005), a 4-criteria approach has been used to guide siting decisions. This 4-criteria approach is summarized as (Mar-Oct hours);

1. (PS 2:1 or greater hrs) to any receptor	< 1.0 % time (59 hrs)
2. (PS 7:1 or greater hrs) to any receptor	< 0.5 % time (29 hrs)
3. Σ_i (PS + S_i 2:1 or greater hrs) to any receptor	< 2.0 % time (118 hrs)
4. Σ_i (PS + S_i 7:1 or greater hrs) to any receptor	< 1.0 % time (59 hrs)

Criteria 1 and 2 limit the odor load to any receptor from the proposed source (PS) to no more than 1% exposure to a weak 2:1 odor (or stronger) and no more than 0.5% exposure to an identifiable 7:1 odor (or stronger). Criteria 3 and 4 are used to assess the cumulative effect from all sources in the community including the proposed source. For this final consideration, all receptors are limited to 2% exposure to a weak 2:1 odor (and stronger) and 1% exposure to an identifiable 7:1 odor (and stronger). Any siting choice not meeting all four criteria for all receptors in the community is relayed to the farmer.

If the 4-criteria approach is applied to the community situation shown in figure 1, three of the 20 receptors had at least one of the 4-criteria exceeded. These receptors were R9, R10, and R15. With the data shown in table 1, R9 exceeds criteria 4, R10 exceeds criteria 2, and R15 exceeds criteria 3 and 4. Note that R15 odor exposure was the result of a prior siting (S1) with very little added odor exposure from PS to R15.

For the case study presented, the farmer made the decision to move the actual construction of PS to a location further south because of the results predicted between PS and receptors R9 and R10. Once PS was moved, all four criteria were met for R9 and R10. It should be noted that the 4-criteria approach established is very conservative for the receptor as it should be in pre-planning applications. This is an important reason why the approach prescribed in this paper with the four criteria given above *must not be used to assess existing source situations*. This is an extremely important aspect of pre-planning siting tools; they should be conservative for the receptor but not applied in such a manner as to implicate farmers who built under pre-existing criteria.

The implementation of CAM is more involved than other proposed siting tools (Guo et al., 2001; Jacobson et al., 2003; Koppolu et al., 2004; Schulte et al., 2004). The experiences gathered from the collaboration between CSIF and IPIC clearly indicate that the majority of siting choices do not need a full CAM modeling run to properly assess a siting choice. To accommodate cases where a low-cost field assessment can be made, a series of odor plots were developed for thirteen regions in Iowa. A typical odor plot is shown in figure 2. Figure 2 represents the odor plot for a 2,500-head DPSF located near Algona, Iowa for receptors located 610 m (2,000-ft) from the proposed source, in any direction from the source. Each plot ring represents a 1% increase in March to October odor exposure hours. The two inner circles represent the 0.5% and 1% criteria corresponding to criteria 1 and 2 as described before.

Two odor profiles are shown in figure 2. The outer odor plot shows exposure hours for weak and greater (≥2:1) odors with the inner odor plot corresponding to identifiable and greater odors (≥7:1). For example, if a receptor exists 610 m due north of the proposed site, CAM would predict a 2.4% time exposure to weak and greater odors and a 1% time exposure to identifiable and greater odors. Both of these exposure levels exceed the criteria 1 and 2 levels. If instead a receptor is located southwest of the proposed source, at a distance of 610 m, the exposure to weak and identifiable odors fall below the criteria 1 and 2 levels.

Odor plots like that shown in figure 2 have been developed for thirteen regions in Iowa, and within each region odor plots have been generated for 2,500, 5,000, and 7,500-head DPSF facilities at receptor distances between 457 m (1,500 ft) and 1,220 m (4,000 ft), in 152 m (500 ft) increments. These odor plots in-turn can be used and implemented by field staff to assess potential siting options. When situations arise where odor plots can not be used to assess siting options, a full CAM modeling run is required. For example, if a siting decision is being made in a community with existing sources, the odor plots developed can not be used, requiring a full CAM modeling assessment.

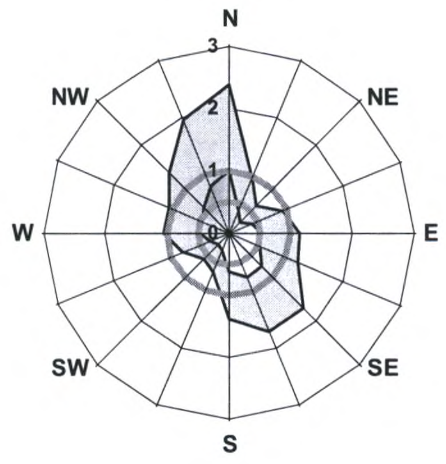
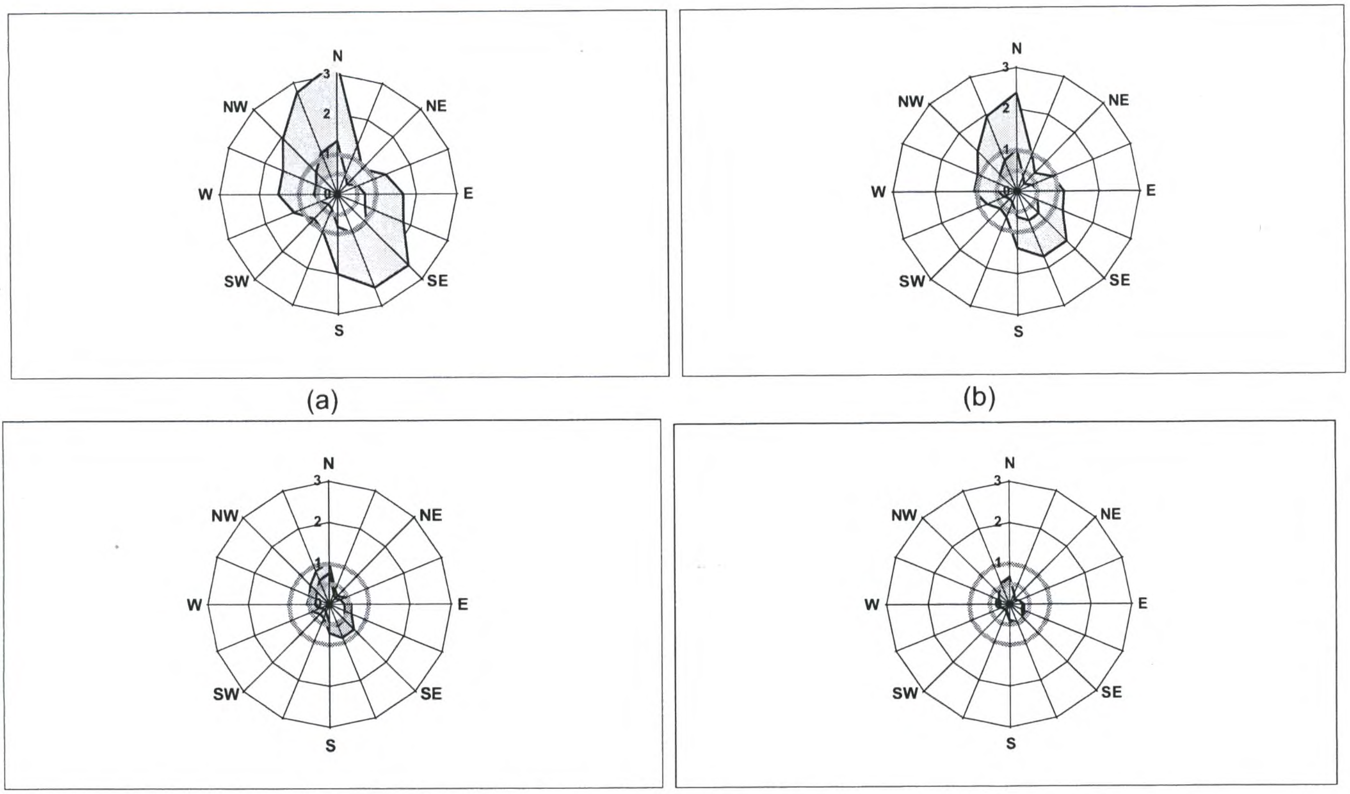


Figure 2. Odor plot for a 2,500-head deep-pit swine finisher located near Algona, Iowa valid for receptors at a separation distance of 610 m (2,000-ft).

Figure 3 presents Algona, Iowa odor plots for a 2,500-head DPSF with four increments of receptor separation distances. One of the useful features with odor plots is that a visual image of the importance of separation distance can be readily demonstrated. The impact of incremental 152 m (500 ft) separations as shown in figure 3 is dramatic. This fact is important if discussions of unreasonably far separation distances surface. Odor plots can help dispel concerns. The natural reaction with legislation for example is to increase separation distances unreasonably as a conservative approach. Using odor dispersion modeling, along with summary odor plots, the benefits of small incremental increases in separation, or, the placement of sources relative to receptors that experience a small percentage of odors based on historical weather patterns can be readily demonstrated.



(a) (b)

(c) (d)

Figure 3. Example odor plots for a 2,500-head DPSF located near Algona, Iowa. The plots show directional effects for this facility at separation distances of (a) 457 m (1,500 ft), (b) 610 m (2,000 ft), (c) 762 m (2,500 ft), and (d) 915 m (3,000 ft).

Technology Summary:

The technology described in this paper uses odor dispersion modeling, combined with local historical weather data, receptor and existing source locations, and a criteria for assessing odor loads to each receptor to assess proposed swine production siting.

Additional Resources:

Additional details related to CAM can be found in Hoff et al. (2003) and Hoff et al. (2008).

Acknowledgments:

The authors would like to thank the Iowa Pork Producers Association, the Iowa Farm Bureau, the USDA-NRI research grants program, the USDA-Special Grants research program, the Iowa State University College of Agriculture and Life Sciences, the Coalition to Support Iowa's Farmers, and the Iowa Pork Industry Center for providing funding for this research and implementation effort. Special thanks to Rex Hoppes of the CSIF and Colin Johnson of the IPIC for in-field implementation efforts using CAM.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
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The Use of Vegetative Environmental Buffers for Livestock and Poultry Odor Management

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Species:	Swine, Poultry, Beef, Dairy
Use Area:	Animal Housing and Manure Storage
Technology Category:	Environmental Barriers
Air Mitigated Pollutants:	Particulate Matter, Odor and Ammonia

Description:

An odor mitigation technology that is drawing a lot of attention in Iowa and in other livestock producing states is the strategic use of shelterbelts – purposefully planted trees and shrubs usually arranged in linear patterns; a technical term for shelterbelts being used for odor mitigation is Vegetative Environmental Buffers or VEBs (Malone et al., 2006). Research evidence suggests that VEBs strategically located near and around livestock facilities can play an important incremental role in bio-physically and socio-psychologically mitigating odor in an economically feasible way (Tyndall and Colletti, 2007).

Mitigation Mechanism:

To a large degree the current livestock odor problem is characterized by high concentrations of odorous emissions (Volatile Organic Compounds – VOCs) that travel mostly unimpeded across highly modified agricultural landscapes. Research has demonstrated that tree barriers can impede, alter, absorb, and/or dissipate odor plumes and other emissions prior to contact with people. As air moves across vegetative surfaces, leaves and other aerial plant surfaces remove some of the dust, gas, and microbial constituents of airstreams. Trees and other woody vegetation are among the most efficient natural filtering structures in a landscape in part due to the very large total surface area of leafy plants, often exceeding the surface area of the soil containing those plants upwards of several hundred-fold (Tyndall and Colletti, 2007).

Vegetative Environmental Buffers have been shown to incrementally mitigate odors, particulates, and ammonia through a complex of dynamics (Tyndall and Colletti, 2007; Lin et al., 2006; Patterson et al., 2007). Among the most important dynamics are: 1) enhancement of vertical atmospheric mixing through forced mechanical turbulence – leading to enhanced dilution/dispersion of odor; 2) odor filtration through particulate interception and retention – odor largely travels by way of particulates; capturing particulates also captures odors; 3) odor/particulate fallout due to gravitational forces enhanced by reduced wind speed; 4) adsorption and absorption of ammonia onto and into the plant – this is due to a chemical affinity that ammonia has to the waxy coating on tree leaves; 5) softening socio-psychological responses to odor due to improved site aesthetics and creating "out of sight, out of mind" dynamics; and 6) improved producer/community relations by using highly visible odor management technology.

The quantification of odor mitigation via the use of VEBs is a difficult process and is approached in a multi-analytic way by means of field trials, wind tunnel examinations and computer simulation. Field quantification is particularly difficult and explains the general paucity of data available for assessment (Colletti et al., 2006). Still, a few studies have recorded incremental mitigation benefits in the form of reduced particulate and odor movement downwind. For example, at a working pullet facility in Delaware Malone et al., 2006 analyzed the impact of a simple VEB and recorded a 49% reduction in particulate movement, a 46% reduction in downwind ammonia concentration, and a 6% (but not statistically significant) reduction in downwind poultry odor concentration. Lin et al. (2006) discusses a 22% reduction in downwind swine odor distance and states that odor concentration was reduced by a factor of three in a series of Canadian field studies examining VEBs. Wind tunnel and computer simulations have also quantified reduced particulate and odor movement due to the presence of strategically located trees (Laird, 1997; Lammers et al., 2001); for example, at Iowa State University, Laird (1997) recorded via wind-tunnel modeling a 56% reduction in off-farm dust movement. Figure 1 below displays the general bio-physical dynamics.

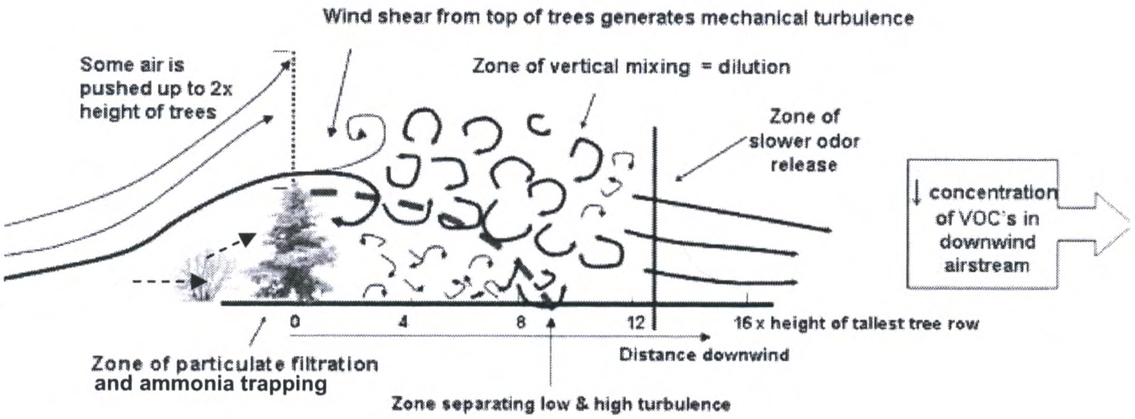

Figure 1. Generalized schematic of VEB odor mitigation dynamics. Note that the magnitude of dynamics listed in text above and shown here are site and VEB specific.

Applicability:

VEBs have been examined primarily in swine and poultry contexts (e.g. swine: Tyndall and Colletti, 2007; poultry: Malone et al, 2006), but have also been recommended for dairy producers (Bolinger and May, 2006). As an odor mitigation technology VEBs have advantages over many other approaches in terms of application. VEBs are adaptable to the landscape and production variability of different livestock production sites and production regions and are amenable to use near or around all sources of livestock odors (e.g. animal buildings, manure storage areas, and crop land receiving manure applications). A VEB is a technology that can be considered production technology neutral, in that producers who raise animals in a variety of ways—confinement (mechanically or naturally ventilated), hybrid confinement, hoop house, pasture—can plant designed VEB systems. There is also information that the presence of trees in agricultural landscapes has socio-aesthetic advantages that most other odor mitigation technologies lack completely (Tyndall and Colletti, 2007). VEBs are a size neutral odor mitigation technology, that is, production sites of all scales can plant trees. Furthermore, as opposed to other odor mitigating technologies that are mechanistic and tend to depreciate over time with concomitant higher maintenance requirements and cost, VEBs may be the only odor control technology that theoretically increases in effectiveness over time. The effectiveness of VEBs in mitigating odor comes from providing complex ecological infrastructure within an otherwise ecologically simplified system. As the trees grow larger and more morphologically complex their ability to mitigate odors through particulate filtration and increased landscape turbulence can become increasingly efficient. Of course, this implied improvement over time is contingent upon the long term health and management of the VEB system and continuance of appropriate manure management.

Limitations:

The physical effectiveness of VEBs in mitigation is extremely site specific and ultimately a function of a myriad of factors: VEB design, ambient weather conditions, landscape topography, direction and distance to nearest critical receptor (e.g. neighbors, communities), scale of emissions, manure management protocols followed and other odor mitigation technology utilized. Therefore, from an odor mitigation perspective, site specific VEB design is of critical importance. There is also a distinct difference between a production site that has a strategically designed VEB and a site that simply has "trees on it". Studies have shown that "strategically" placed trees have a beneficial physical impact on downwind odor (Tyndall and Colletti, 2007), whereas trees used simply for visual landscaping or are naturally part of the landscape may not (Nicolai et al., 2004). Furthermore, "mitigation" does not mean odor elimination and the degree to which VEBs contribute to odor mitigation will vary from farm to farm. While VEBs have been shown to contribute in incrementally reducing the downwind concentrations of odorous chemicals/ compounds and particulates, what this means to the highly subjective perception of odor being a "nuisance" is a very difficult question to answer. The benefits of the incremental contribution of VEBs to odor reduction are likely to be found in variously reducing the combined effects of the FIDO factors of an odor event – the frequency, intensity, duration, and offensiveness of odor. Therefore the use of VEBs is not a substitute for comprehensive odor management strategies rather their use should be thought of as complimentary technology used within a "suite" of odor management strategies.

Cost:

Costs for VEB systems are highly variable and are site/design specific. There are three main categories of expenses associated with VEBs: 1) Site prep costs, 2) tree establishment costs, and 3) long term maintenance costs. Table 2 below outlines the typical expenditures that a producer might expect in establishing and maintaining a VEB system. It should be noted that the majority of the total cost (usually in the range of 40-70%) is "upfront" and is tied to the cost of the initial planting stock (e.g. older, larger nursery stock can be considerably more expensive than bare-root seedlings but such an investment may "buy time" in VEB establishment). Long term maintenance costs vary depending upon the design and overall health of the VEB. It should be recognized that there are expenditures that occur regularly throughout the life of a VEB and maintenance is an annual process, however as a VEB system matures the annual maintenance requirements will likely decrease over time.

Table 2. Custom rate survey of typical VEB transaction costs and year(s) in which they occur.

Cost item	Year(s)	Price/ Unit [1] (US 2008 $)	Source of Price Information [1]
Site Prep			
Plowing	0	$13.60/ac	a
Spray purchase	0	$1.25/ac	b
Spraying operation	0	$19.00/ac	c
Disking	0	$20.00/ac	c
Shelterbelt Establishment			
Tree purchase costs	1	Variable [2]	d,e,f [2]
Shrubs purchase cost	1	Variable [2]	d,e,f [2]
Tree planting cost	1	$1.00 – $5.00/tree	c
Shrub planting cost	1	$1.00 – $5.00/tree	c
Permeable plastic mulch	1	$633/linear mile	g
Long Term Maintenance			
Tree replanting	2-4	Variable [3]	d,e,f
Shrub replanting	2-4	Variable [3]	d,e,f
Weed control (e.g. mowing)	Annual	$31.46/linear mile	c
Tree Pruning	Every 3-5 years	$31.46/linear mile	c
Other relevant costs			
Overhead/management [4]	Annual	Variable	-
Land rent [5]	Annual	Variable [5]	h

[a] Iowa State University, 2008.; [b] Based on 2008 cost of 2.5 gallon container of generic glyphosate; [c] Iowa State University, 2003; [d] Cascade Forestry Nursery, 2007; [e] Kelly Tree Farm (online catalog), 2008; [f] Iowa Department of Natural Resources, 2007; [g] PFRA, 2008; [h] Iowa State University, 2007.

[1] Units are variable depending upon cost item; prices listed as per linear mile assume a treatment strip of 10' by 5280' or a "price/ acre" to "price/ linear mile" conversion factor of 1.21. All costs include labor and fuel where relevant. Unless otherwise given, all listed costs represent an average price presented in the various Custom Rate Surveys used; [2] Species and plant size specific; [3] It is assumed that tree and shrub mortality will equal 8% during the second through the fourth years after establishment; [4] Includes taxes, insurance, energy requirements, etc; [5] If any land is taken out of production for the planting of a VEB then land rent should be factored in.

Implementation:

When implementing a VEB, there are several key design issues. A proper VEB can serve as both a visual screen and an odor filter. To this end, one needs to account for prevailing summer and winter winds and key visual pathways (e.g. screening a manure storage area from passing traffic). Key planting zones can then be identified so as to maximize the effects of filtration and increased turbulence and provide screening from desired angles and directions. See Figure 2 below for an example VEB design and Table 3 for a financial analysis of this example system.

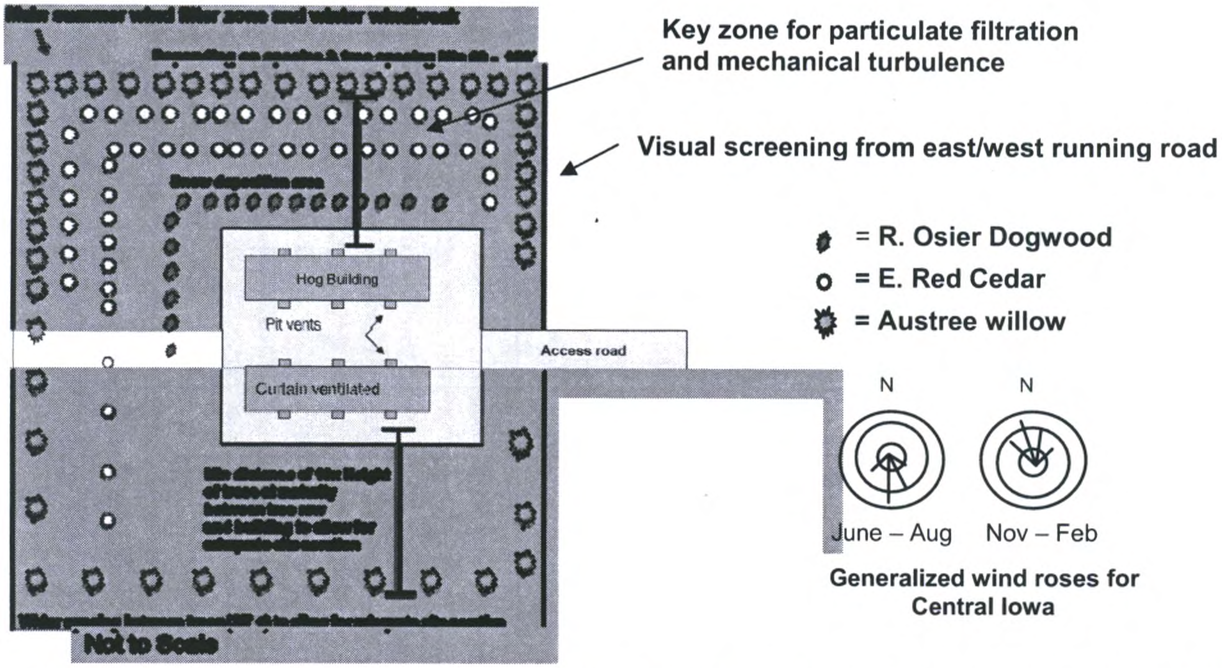

Figure 2. Example general VEB design for a two building swine finishing unit. VEB is designed for Central Iowa wind patterns. Ultimately VEB designs (e.g. planting patterns, locations, species used) will be variable and site specific. Figure modified from Tyndall and Colletti, 2007.

The calculated costs of the example VEB (Figure 2) are presented in a number of ways in Table 3 below. The present value of costs (at 7%) for each scenario was calculated to capture the total costs of establishing and maintaining the shelterbelts over a 20 year period. This was calculated with and without land rent factored in. Because 40% of the total costs of this example VEB comes during the site preparation and establishment phase (primarily from the costs of the planting stock) these "up-front" costs are isolated and presented. Total costs were also calculated as annual capital recovery payments (total costs in the form of uniform annual payments over a 20 year period). Additionally, costs per pig produced are also presented.

Table 3. General shelterbelt parameters and financial analysis for VEB in Figure 2. Summary of the total costs at 7% (real alternative rate of return). All costs are presented in 2008 dollars US.

Figure 2 VEB				Cost Presentation for Figure 2 VEB	
Total trees planted	140	81	33	Present Value Costs w/o land rent	$1,741
Space between trees (feet):	6 - 25'	15 - 25'	6'	Present Value Costs with land rent	$2,452
Species planted	Austree willow	Eastern red cedar	R. Osier Dogwood	Upfront costs (Site prep & establishment only)	$737
Initial planting stock size [1]	15" cutting	18"-24" bare root	2'-3' potted	Capital Recovery Costs (Annual cost over 20 years)	$164
General growth rate for species [1]	Very fast; 5-10 ft/yr	Medium; 1-2 ft/ yr	Medium to fast; 2+ ft/yr	Total costs per pig produced over 20 yr period	$0.05/ pig

[1] Larger planting stock is more expensive but with these initial stock sizes in 3 years Austree willow ≈ 25'-30'; Red cedar ≈ 6'- 9'; Red osier Dogwood ≈ 4' - 5'. Growth rates, however, are variable depending on site conditions, health of planting stock and region.

For the VEB shown in Figure 2 above, a VEB system as outlined in Table 2 would cost a producer over a 20 year period a little over $1,741, with about $737 (42% of the total cost) coming during the initial establishment phase. These total costs translate to about $0.05 per pig produced.

All VEBs need to be established in appropriately prepared planting areas (see section below on site preparation) using regionally appropriate nursery stock. As suggested in Table 2 above, all VEBs should have a well thought out long-term maintenance plan to ensure the overall health of the system and to keep long term costs/labor down. Another key design factor is mixing the species used. This is recommended for two main reasons: 1) increased species diversity reduces the risk of whole scale pest/pathogen loss, and 2) some species (e.g. hybrid willows and poplars) feature very rapid growth but often have relatively short healthy life spans (e.g. 15-20 years), mixing in slower growing but longer lived species will allow for a robust and mature VEB system to remain after other species are removed.

There are three main hazards that must be avoided when utilizing VEBs yet these are all easily avoided with proper VEB design and implementation. VEB designs need to prevent: 1) winter snow deposition problems by planting trees too close to access roads and buildings. In Central Iowa for example winter winds largely come from the North/Northeast. Therefore VEBs planted to the north and east of buildings/roads should plan for a planting distance anywhere from 50-200' away. 2) Trees should not be planted so close to buildings that they prevent appropriate air flow into and out of the buildings. For mechanically ventilated buildings trees can be planted as close as 5-6 times the diameter of the fans and avoid causing back pressure, but that distance may not be healthy for the trees. A minimum distance of 40 feet away from fans has been recommended (Malone et al., 2006). For naturally ventilated systems, one does not want to impede necessary summer winds (which in Central Iowa tend to come from the South/South east) blowing into the buildings. 3) Visibility into and out of the facility grounds is important, so keep the mature heights of trees in mind when planting trees near access roads.

Appropriate site preparation is one of the main keys to the long term health of tree plantings and will contribute toward lower tree mortality, faster tree growth and ultimately, lower time, money and effort in managing the system over the life of the operation. In many cases the grounds of a livestock facility - the area where trees are to be planted – features highly compacted soils, subsurface soil piling, poor drainage, etc. Many VEBs fail (e.g. high tree mortality) because of inadequate site preparation. When planting trees directly into tilled crop ground, site preparation requirements will likely be lessoned. Table 4 below outlines possible site preparation requirements prior to tree planting. It is always recommended that a producer seek advice from a forestry professional before proceeding with a VEB system.

Table 4. Generalized site prep requirements prior to tree planting for new livestock facilities:

1 year before VEB establishment (Fall: Oct-Nov):	Year 1 (Spring – late April/Early May)
– 4' Kill strip (e.g. Round Up)	– Disk/ cultivate again & if possible rototill
– Disk/cultivate (work soil to 8" depth)	– Soil should have no clumps & minimal residue
– Seed cover crop (e.g. clover, rye)	– Grass seed may be desired (sow outside of mulch and or weed mat zones)

Technology Summary:

Tree based Vegetative Environmental Buffers (VEBs) can be a cost-effective way for livestock producers to incrementally mitigate odors, particulates and ammonia emanating from their sites. Research supports the possibility of 6-15% reduction in odor and in certain situations possibly up to 50% reduction in ammonia and particulates. As air moves across vegetative surfaces, leaves and other aerial plant surfaces remove some of the dust, gas, and microbial constituents of airstreams while increased mechanical turbulence can boost the vertical mixing of air streams thereby enhancing dilution. VEBs are relatively inexpensive and straight forward to manage and therefore in many cases can easily fit into current odor management plans. While the physical effectiveness of a VEB in mitigating odors and the overall expense of establishing and managing a VEB are highly variable and site specific, their use can incrementally enhance (in an additive way) a livestock production system's ability to reduce negative odor impacts for just a few cents per animal produced.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
Iowa Farm Bureau Federation
Iowa Egg Council
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U.S. Pork Center of Excellence

Efficacy of Vegetative Environmental Buffers to Mitigate Emissions from Tunnel-Ventilated Poultry Houses

G. Malone, G. VanWicklen, and S. Collier
University of Delaware

Species: Poultry (Broiler, Layer, Turkey)
Use Area: Animal Housing
Technology Category: Environmental Barriers
Air Mitigated Pollutants: Ammonia, Dust and Odor

Description:

Poultry farms are facing unprecedented challenges! Emissions of ammonia, dust, odor, and noise from poultry operations are an increasing concern from both a neighbor-relations and an environmental standpoint. Odor, dust, feathers, and noises associated with poultry operations are issues the poultry industry must deal with to maintain good neighbor-relations. With more frequent use of tunnel fans during warm weather and more outdoor activities by neighbors, summer is often a critical time for nuisance complaints to surface. During the past few years, there have been an increasing number of legal cases involving nuisance complaints associated with neighbors next to, and downwind of tunnel-ventilated poultry houses. At the same time we are seeing an increase in human population in many poultry producing areas. As many poultry producing areas in the USA become more urbanized, the likelihood of increased nuisance-related complaints will only increase. These issues are exacerbated as the size of our poultry farms increase.

To further add to the poultry industry's future challenges, emissions from poultry houses may be regulated in the future. The National Ambient Air Quality Standards under the Clean Air Act has been revised to include a particulate matter standard of 2.5 μm diameter. Both ammonia and dust may fall under this regulation. In some coastal areas of the U.S. there is the added concern that ammonia emissions from poultry houses may be a significant source of atmospheric nitrogen and this source of nitrogen may stimulate algae growth particularly during the summer.

The adoption of sound, practical, efficient, and cost-effective technologies to address neighbor-relations and environmental issues will be increasingly important in the poultry industry. One such technology is a vegetative environmental buffer (VEB). A VEB is a strategic planting of combinations of trees and shrubs around poultry houses to meet specific objectives on each side of the farm. The poultry industry has not previously recommended the planting of tall crops, shrubs, or trees around houses fearing they will interfere with natural ventilation during the summer in open sidewall housing. However, this no longer a major concern as industry shifts to tunnel ventilation, black-out, and totally enclosed housing systems.

The three basic goals in the design of a VEB planting are a visual screen, windbreak and shade, and vegetative filter (Figure 1). As described by Malone and Donnelly (2001), a VEB may foster improved **neighbor-relations** by filtering dust, feathers, odor, and noises from houses; provide a visual screen of the houses and the routine farm activities; and improve public perception of the industry via a proactive, "green" initiative. Potential **environmental** benefits include a reduction in ammonia, dust, odor, surface, and groundwater nutrients leaving the proximity of farms, and a practice that promotes carbon sequestration. A properly designed VEB program may also have **production** benefits for tunnel-ventilated poultry farms. Trees strategically planted for windbreaks, shade, and to filter air-borne pathogens offer potential energy conservation and improved farmstead biosecurity.

Mitigation Mechanism:

In the review by Tyndall and Colletti (2000), they reported shelterbelts ameliorate odors by dilution, encourage dust and aerosol deposition by reducing wind speeds, physical interception of dust and aerosols, and act as a sink for chemical constituents of odor. They also concluded shelterbelts have the potential of being an effective and inexpensive odor control technology particularly when used in combination with other odor control methods. Furthermore, plant foliage has the capability of utilizing ammonia through its stomata by means of glutamine synthetase-glutamate synthase pathways (Yin et.al, 1998). Patterson et al (2006) recently found a VEB consisting of hybrid poplar and Norway spruce opposite poultry house fans were able to trap aerial ammonia emissions in plant tissue. As shown in Figure 2, leaves, particularly conifers with complex leaf shape, also have the ability to capture particulates emitted from poultry house fans.

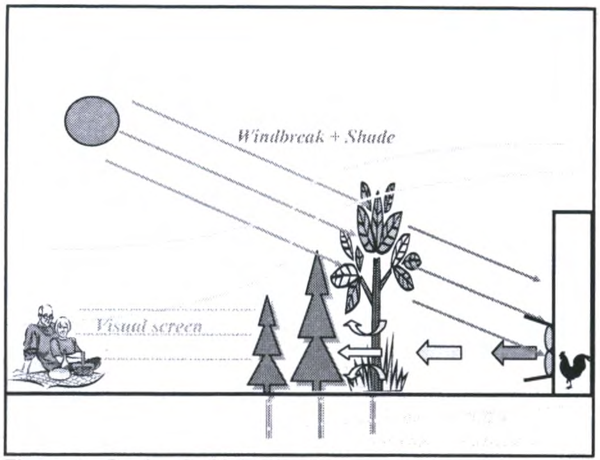

Figure 1. Goals of a VEB planting around houses.

Figure 2. Dust accumulation on conifers opposite fans.

Applicability:

Although the focus of this VEB research has been on mitigation of emissions from tunnel-ventilated poultry houses, it would also have application for other power-ventilated, totally enclosed livestock housing. In 2002 a three-row planting of trees was installed opposite two, 1.2 meter (4 ft) diameter tunnel fans to evaluate vegetative environmental buffers (VEB) as a means of mitigating emissions from poultry houses. The first row, 9.1 meters (30 ft) from the fans was 4.8 meter (16 ft) high bald cypress, followed by 4.3 meter (14 ft) high Leyland cypress and the outer most row of 2.4 meter (8 ft) high Eastern red cedar. Over the next six years the efficacy of these trees to reduce total dust, ammonia and odor was determined. Measurements were taken at 1.2 meter (4 ft) height on 47 days during peak fan operation with market-age broilers. The relative change in concentration across this 6.7 meter (22 ft) wide vegetative buffer found the VEB significantly reduced total dust, ammonia and odor by 56%, 54% and 26%, respectively. Wind direction relative to the fan plume and the type of crop next to the VEB appeared to influence the efficacy of vegetation to reduce odor. The reduction in odor by the VEB "appeared" to be less when winds were blowing towards the fans and when the crop adjacent to the VEB allowed better dispersion of the odor plume. Dust and ammonia concentration was influenced by these factors to a lesser degree.

Limitations:

The selection of plant material and their arrangement must be designed for each side of the poultry house, for each farm and must address the following goals of the program; vegetative filter, visual screen and shelterbelt. The minimum distance of the VEB from fans appears to be 10 times the fan diameter. Deciduous trees or evergreens with waxy leaves planted as the first row opposite fans tend to withstand the high-particulate loads best. To insure livability and maximize growth of the VEB, an effective irrigation and weed control program is essential. Poultry farmers are strongly encouraged to seek technical assistance in the design, implementation and maintenance of a VEB. Retrofitting a VEB around existing houses poses many challenges due to boundary, structural, traffic patterns and other land-use restrictions. The ideal time to plan and install a VEB is before construction of the poultry houses.

Cost:

Average cost for implementing a VEB on an existing broiler farm is ~$5,500. Cost range from $1,500 for a limited one-row planting to provide a visual screen of the farm, and up to $12,000 for multi-row plantings around the outside perimeter of the poultry houses. There is limited information on design and efficacy of VEB plantings between houses. Locally, cost-share programs have provided support to cover most of the costs associated with implementing this program.

Implementation:

Plantings to address neighbor-relations have been a driving factor in VEB establishment. An estimated 1/3 of all poultry farms have established VEB on the Delmarva Peninsula. A VEB is also a requirement for a new house loan from one of the major lending institutions. In an effort to be responsive to escalating neighbor-relations and emissions issues, the local poultry industry has hired a coordinator to promote, develop literature (*i.e.* VEB Tool-Kit, 2007); and facilitate in the design, installation and maintenance of VEB on poultry farms. Other regions of the USA such as Pennsylvania and Iowa are also actively involved in research and implementation of VEB for poultry and livestock farms.

Technology Summary:

Vegetative environmental buffers appear to be a practical and cost-effective technology to partially abate emissions from modern tunnel ventilated poultry houses. Research to date suggests a properly designed VEB will disperse, capture, assimilate and/or dilute ammonia, dust and odor emitted from fans. They tend to be more effective for ammonia and dust abatement than for odor. Adoption of this practice by the Delmarva poultry industry has been driven primarily by its neighbor-relations benefits. The visual screen aspect of a VEB coupled with a proactive measure to address increasing urban encroachment and air quality issues are driving forces in acceptance of this technology. Poultry farmers are encouraged to seek technical assistance in the design, implementation and maintenance of a VEB. In addition to cost-share and technical assistance from local and state agencies, the regional poultry industry trade association for the Delmarva Peninsula has hired a coordinator to assist with adoption of this program on poultry farms.

Additional Resources:

The Benefits of Planting Trees Around Poultry Farms. http://www.rec.udel.edu/Poultry/tree_buffer.pdf
VEB Tool-Kit. http://www.dpichicken.org/download/VEBTK.pdf
Using Shelterbelts to Reduce Odors Associated with Livestock Production Barns.
http://www.omafra.gov.on.ca/english/crops/facts/info_odours.htm

Acknowledgments:

The University of Delaware received funding to support VEB research from the following:
US EPA Section 319 funds
US Poultry and Egg Association
USDA, NRCS Agro forestry
NRI Air Quality grant with Iowa State and Penn State Universities

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
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Vegetative Buffers for Swine Odor Mitigation - Wind Tunnel Evaluation of Air Flow Dynamics

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Species: Swine
Use Area: Animal Housing
Technology Category: Environmental Barriers
Air Mitigated Pollutants: Ammonia, Hydrogen Sulfide, Volatile Organic Compounds, and odor

Description:

One of the most significant and persistent environmental concerns regarding swine production is odor transport from animal feeding operations and manure storage facilities. Odor constituents include ammonia, hydrogen sulfide, and various volatile organic compounds (VOCs), which may exist as individual gaseous compounds or adsorbed onto particulates (Zahn et al., 1997; Trabue et al., 2006; Tyndall and Coletti, 2006). Building type, facility management, animal diet, and climate affect the amount of potential odor constituents generated at production facilities. Local environmental conditions, especially wind speed and direction, vegetative cover, and topography determine the amount of odor constituents transported downstream from production facilities. Odor mitigation strategies may be designed to reduce either odor generation or transport or both.

As wind approaches a solid object such as a swine-housing unit without any protection upwind, the air accelerates around the sides and over the top of the building diverting air and disturbing the airflow downwind. This additional turbulence around confined swine feeding facilities may increase the downstream transport of odor constituents derived from the feeding facility or stored manure (lagoon, slurry tank, or deep pit). An upwind structure such as a vegetative buffer may protect buildings from excessive wind speed, reduce odor dispersion, and hence produce air quality benefits at a minimal cost.

Prevailing wind direction and speed are two driving factors of odor dispersion around confined feeding operations. Vegetative buffers planted upwind of confined swine facilities may modify air flow dynamics around buildings by decreasing wind speed, and hence diminishing transport of odor constituents. Vegetation is also capable of physically trapping particulates intersected as they flow through the plant canopy.

In addition to the potential mitigation of odor emissions and particulate transport from swine facilities, other benefits from using vegetative buffers include: tree products (e.g. firewood), aesthetics, snow control, wildlife habitat, buffers for extreme temperature fluctuations, soil C sequestration, and potential soil erosion control.

Mitigation Mechanism:

Vegetative buffers are one technique available for diminishing wind velocity, capturing particulates and reducing odor transport from swine production facilities (Malone et al., 2004; Tyndall and Coletti, 2006). Single or multiple rows of trees near swine feeding facilities can reduce odor transport by intercepting gaseous compounds and particulates. Vegetative buffers upwind of swine facilities may also reduce wind speed causing the odor constituents to be deposited on the land surface. Forest vegetation is an efficient natural air filter due to the large amount of surface area on leafy plants. Studies on urban woodland species found conifer trees to be more effective than broadleaf trees and hairy leaves more effective than smooth leaves in capturing particulates (Beckett et al., 2000).

Applicability:

Adding a vegetative buffer to a swine production facility has great potential to reduce air quality impacts and can be accomplished with a modest installation cost and a small increase in annual operation costs. Fig. 1 shows a model of the swine farm employed as a case study in our experiments including vegetative buffers in both north and south sides of the buildings.

Data from simulation studies (see details for wind tunnel study in implementation section below) show the extent to which the application of vegetative buffer technology can decrease wind speed around swine feeding operations (Fig. 2). These experiments showed definite benefits of vegetative buffers on air flow dynamics around swine facilities.

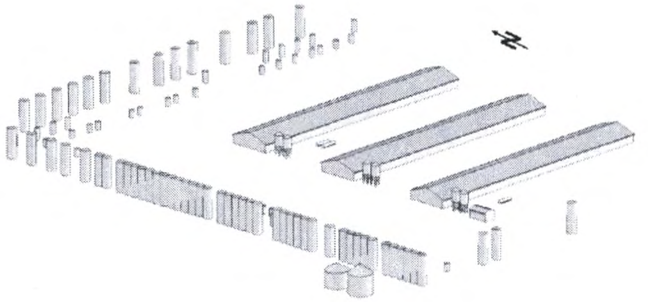

Figure 1. Model of a swine facility located in Boone County, IA. Prevailing wind direction from south west in summer and north west in winter. Cylinders west and north of the buildings represent trees (See description below in implementation section).

Limitations:

Swine confinement facilities should have an adequate air exchange with the surrounding atmosphere to assure proper animal growth and comfort. To reduce air flow around confined feeding facilities by improper planting of vegetative buffers (perhaps more than 3 dense rows) may limit the required heat exchange and compromise animal performance. Criteria for design and establishment of vegetative buffer (density, species selection, arrangement) should consider air circulation near and through buildings to promote animal comfort and development.

Field studies on air flow dynamics around confined animal feeding facilities are limited due to the large number of potential building arrangements, varying land cover, and topography. Therefore, studies on the transport of air quality constituents from buildings of various types have often been conducted in wind tunnels (Huber and Snyder, 1982; Huber, 1989). Low speed wind tunnels (LSWT) offer the advantage of being able to make detailed measurements with scale models of actual buildings under controlled environmental conditions. Some studies combine wind tunnel and field measurements (Mavroidis et al., 2003; Aubrun and Leitl, 2004b) and have generally shown that careful wind tunnel experiments provide an accurate and reproducible assessment of field conditions. Thus, scale model studies in a LSWT may offer a powerful cost-effective approach to assess numerous combinations of vegetative buffer and buildings as well as to develop general guidance for vegetative buffer design around swine confined facilities.

Our LSWT experimental setting facilitates comparative evaluation across diverse stable scenarios what would be very complex to complete in field studies. However, LSWT setting may impose few limitations to this study. Simulation scale models (1:150) of both vegetative buffers and buildings models may not be a precise representative of field conditions with respect to air flow dynamic. In addition, LSWT setting operates at constant wind direction and speed, while both direction and speed of wind are highly fluctuating in most field conditions. Nonetheless, wind tunnel simulations are appropriate proxies for relative comparison across diverse swine facilities scenarios, and it is a cost effective method to evaluate numerous combinations of vegetative buffer designs.

Cost:

The cost estimates for vegetative buffers around swine facilities encompasses site preparation, planting stock, establishment, maintenance (long-term management), and overhead. These costs were calculated for three different scenarios of vegetative buffers (Table 1) planted around a swine finishing facility employed as a case study (see model of the farm in Fig. 1) with the assumption that each scenario accepts the same level of investment risk, and over a period of 20 years with and without land rent factored in (Table 2).

Table 1. Vegetative buffer parameters by planting scenario.

	Scenario 1			Scenario 2	Scenario 3
Number of tree rows		3		1	1
Total trees	Row 1	Row 2	Row 3	113	113
	113	34	34		
Space between trees (feet)	9'	30'	30'	30'	30'
Species planted	Austree willow	Eastern red cedar	Jack pine	Austree willow	"Mixed hardwoods"[1]
Initial planting stock size	15" cutting	2-3' potted	2'-3' potted	15" cutting	1 year potted

[1] Native Iowa hardwoods: includes poplar, silver maple, hackberry, and black cherry.

Upfront costs (site preparation and establishment phase) were more than 50 % of the total costs to producers in each scenario (Table 2). These upfront costs were primarily due to costs of the planting stock. Costs of initial planting stock (sizes as described in Table 1) were 0.75, 18, 18, and 9 dollars for austree, eastern red cedar, jack pine, and hardwoods, respectively. Two additional upfront costs were planting operation ($1.00 per tree) and site preparation ($53.85 per acre). Site preparation included plowing, spraying, and disking. Other establishment costs were plastic mulch ($633/linear mile) and spraying ($20.25 per acre). Maintenance (weed control at $31 per linear mile, and replanting at 8 % mortality through fourth year) was also included in the financial analysis as well as overhead ($18 per year). Annual land rent was estimated as $100 per acre for tillable pasture.

For Scenario 1, the three row vegetative buffer system would cost a producer over a 20 year period just over $3,000, with just under $1,800 coming during the initial establishment phase. These costs translate to about $0.03 per pig produced. Scenario 2 featured a single row of Austree willow and would cost $460 over a 20 year period with half of the costs coming upfront; costs per pig are less than 1 cent per pig produced. Scenario 3 featured a single row of mixed hardwoods and would cost about $1,700 over a 20 year period with the vast majority (70 %) of the costs coming upfront; costs per pig come out to about $0.02 per pig (Table 2).

Table 2. Costs for each vegetative buffer scenario at 7% real alternative rate of return (RARR) and in 2008 dollars US.

	Planting Scenario		
Cost Presentation	1	2	3
Present Value Costs (without land rent)	$3, 039	$460	$1,682
Present Value Costs (with land rent)	$4,416	$1,074	$2,297
Upfront costs (site preparation and establishment only)	$1,786	$231	$1,180
Capital Recovery Costs (annual cost over 20 years)	$287	$43	$159
Total costs per pig[1] produced over 20 yr period	$0.03/pig	$0.005/pig	$0.02/pig

[1] It was assumed that each of the three hog finishing buildings holds 1,200 head and that there are 2.5 turns per year.

It should be noted that with these vegetative buffer scenarios, total costs are contingent upon the initial choice of planting stock, the comparative long-term health and maintenance of the system, and the choice of long-term weed control. With drier soils a drip irrigation system may be necessary and would add roughly $0.01/ per pig produced.

Implementation:

Information reported here concerning the effectiveness and feasibility of diverse vegetative buffer configurations to reduce odor and particulate transport downstream from feeding facilities is based on data from our LSWT studies (117 experimental runs) performed using scale models at wind speeds of 2, 5 and 10 m/s, and measuring of wind profile (2 to 400 mm above the floor of the wind tunnel) with a constant temperature anemometer equipped with a 1-D boundary layer hot film probe located downstream from the feeding operations at distances 1, 2 and 6 times the height of the buildings (1H, 2H and 6H, respectively) similar to Sauer et al. (2006). Measurements were done behind the buildings as well as midway between buildings. As described in the cost section above, three different upstream vegetative buffer configurations were evaluated: three rows of trees (first row of willow trees plus two rows of jack pine/eastern red cedar trees), and a single row of Austree willow trees or hardwood deciduous trees (both scenarios with equivalent total frontal area). All tree scale models (1:150) were constructed using 8 x 8 wire mesh (Aubrun and Leitl, 2004a). Both willow and hardwood models were 60 mm tall while, pine/cedar tree models were between 14 to 24 mm tall. To simulate differences in canopy among tree species, willow/cedar/pine models had a complete double mesh, while hardwood tree models had double mesh only in the upper one-third of the model.

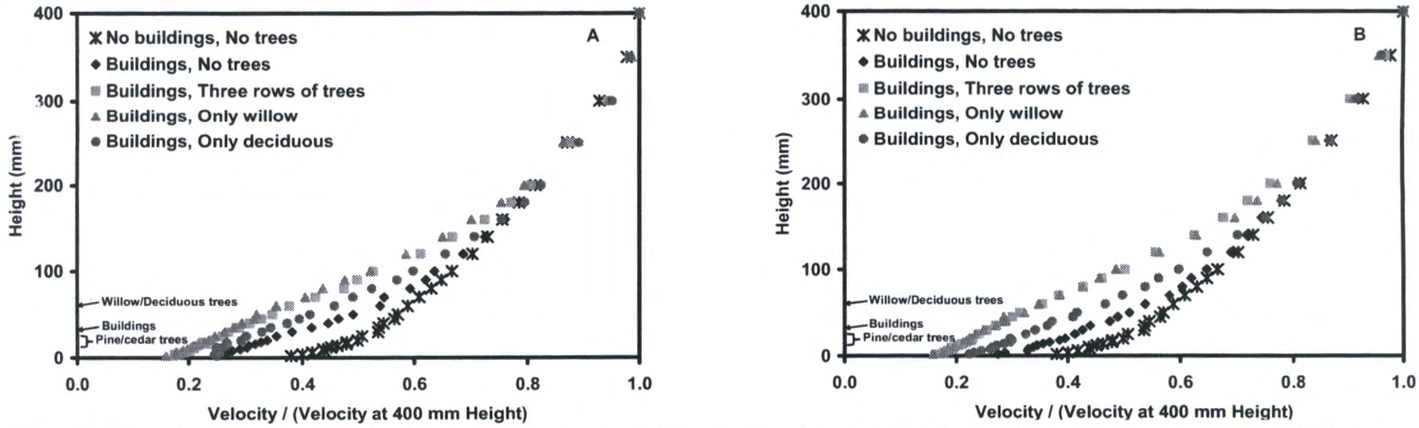

Figure 2. Wind velocity ratio profiles as affected by vegetative buffer configuration at a distance of 6H downstream from the building models at 10 m/s. (A) Behind middle building, and (B) midway between buildings sampling positions.

Our simulation study demonstrated the potential impact of vegetative buffers to substantially reduce wind speed. Fig. 2 shows how three rows of trees or a single row of willow trees can decrease wind velocity twice as much as the buildings alone from the ground surface to 50 feet (0 to 100 mm in our experimental scale).

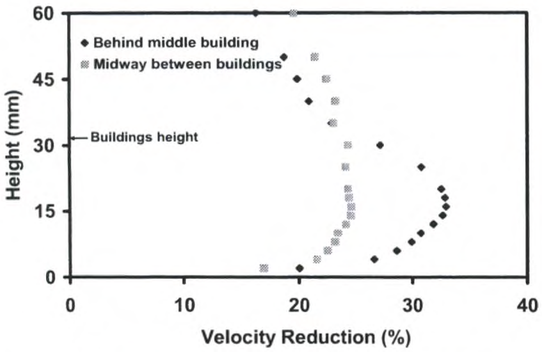

Figure 3. Wind velocity reduction due to building models with two sampling positions.

Buildings alone had a large impact on decreasing wind velocity (Fig. 3). At least 20 % of wind speed reduction was observed in our wind tunnel simulation studies. Measurements done behind the middle building (downstream of air flow) showed a wind speed reduction of about 10% compared to values measured midway between buildings (Fig. 3). However, those differences disappear at heights above the buildings (peak= 15.8 feet) indicating the definitive impact of buildings on air flow dynamic around swine confined feeding operations.

Contribution of windbreaks to wind turbulence (mixing) was found to be 15 to 20 % greater than the contribution by buildings (Fig. 4). In both cases (wind speed and turbulence) a single row of hardwood trees was intermediate between buildings alone and buildings plus three rows of trees or single row of willow trees.

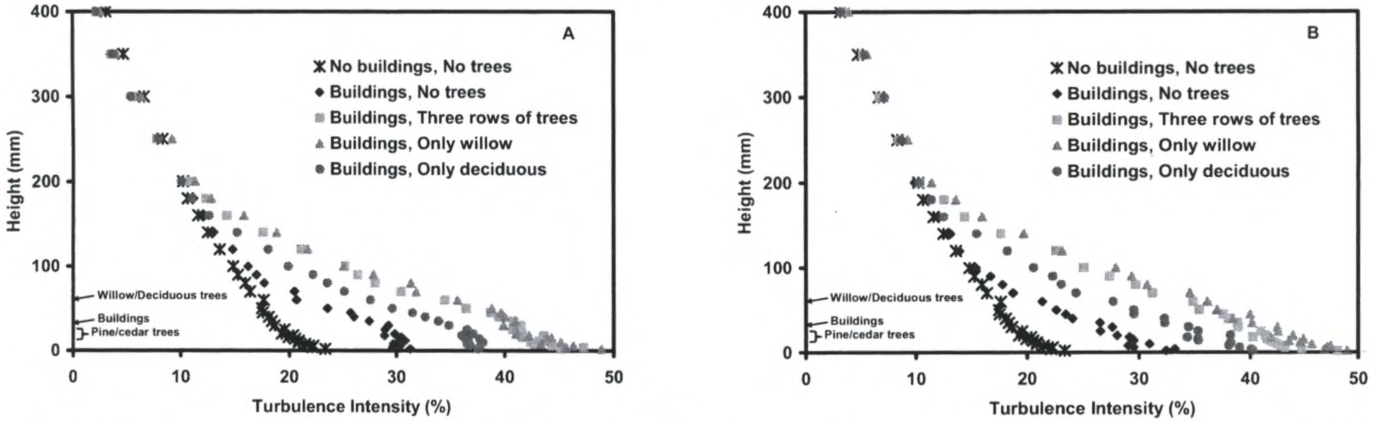

Figure 4. Turbulence intensity profiles as affected by vegetative buffer configuration at a distance of 6H downstream from the building models at 10 m/s. (A) Behind middle building, and (B) midway between buildings sampling positions.

In general, the effect of both buildings and trees on wind speed and turbulence (Fig 3 and 4, respectively) was observed in heights lower than 100 feet (200 mm in our experimental scale). Even more important, the impact of buildings on air flow parameters goes only to a height of 50 feet (100 mm in our experimental scale); however, the combined effect of buildings plus tree rows of trees persists until a height of 100 feet (200 mm in our experimental scale).

Results of these experiments suggest that implementation of vegetative buffers planted upwind can sharply decrease wind speed, and therefore they may reduce transport of odor constituents and particulates from a multiple buildings swine facility. In addition, it is remarkable that a vegetative buffer of a single willow tree row appears to have nearly the same effect as three rows of trees (1 willow + 2 cedar/pine). However, considerations with respect to vegetative buffer longevity and lifetime may justify the inclusion of cedar/pine together with willow trees in a vegetative buffer arrangement.

Additional Resources:

Windbreak and Odor Mitigation
http://www.forestry.iastate.edu/res/odor_mitigation.html

Windbreaks Function
http://www.ianr.unl.edu/pubs/forestry/ec1763.htm

Farmstead Windbreaks: Establishment, Care and Maintenance
http://www.extension.iastate.edu/Publications/PM1717.pdf

Acknowledgments:

We wish to thank Jadon Kool, Kevin Jensen and Dan West for their assistance in this study. Project support was provided by National Pork Board (Project 000).

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
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Animal Housing-Treatment

Mitigating Air Emissions from Animal Feeding Operations
Des Moines, IA May 19-21, 2008
Conference Proceedings

Water Requirements for Controlling Dust from Open Feedlots

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Kansas State University

Species: Beef, Dairy
Use Area: Animal Housing
Technology Category: Management
Air Mitigated Pollutants: Odor and Particulate Matter

Description:

The beef cattle industry has been faced with environmental concerns, including air quality impairment within and downwind of the beef cattle feedlots. Particulate matter (PM) emission is a major factor that impacts air quality from the feedlot and poses health concerns to humans and animals alike. MacVean et al. (1986) linked the health and performance of newly received feeder cattle to the onset and magnitude of dust events. Sweeten et al. (2000) indicated that particulate matter emission annoy neighbors and irritate feedlot employees.

In general, the major source of PM emission from a cattle feedlot is the pen surface. Particulate matter is emitted when cattle hooves trample on the dry, uncompacted layer of manure and soil. Other sources of PM emission are unpaved roads, hay grinding, grain handling, and feed processing, including loading and delivery (Auvermann et al., 2006). Dust problems are most likely to occur during the period of July through September, but can occur whenever extended periods of low rainfall are combined with high evaporation rates to produce surface drying.

Sweeten et al. (1988) monitored the total suspended particulate (TSP) concentration in three commercial cattle feedlots in Texas. They reported overall mean net TSP concentration (i.e., downwind - upwind) 410 $\mu g/m^3$, ranging from 68 to 882 $\mu g/m^3$, for 24-h sampling periods. In addition, for 4- and 5-h time intervals within the 24-h sampling periods, TSP concentrations ranged from 16 to 17,000 $\mu g/m^3$. In a related study, Sweeten et al. (1998) measured the concentrations of both the TSP and PM_{10} (particulate matter with nominal diameter of 10 μm or less) at three commercial cattle feedlots in Texas. They reported mean downwind concentrations of TSP and PM_{10} of 700 $\mu g/m^3$ (ranging from 97 to 1,685 $\mu g/m^3$) and 285 $\mu g/m^3$ (ranging from 11 to 866 $\mu g/m^3$), respectively. Rozate et al (2007) studied the concentrations of PM_{10}, TSP, and odor detection threshold downwind and upwind of a water-sprinkled commercial cattle feedlot in Kansas. This study found the measured PM_{10} concentrations varied considerably with time. PM_{10} concentrations were generally larger during the early evening hours within a given day and during the summer months. Odor DTs, upwind and downwind of the feedlot, varied considerably with sampling period and ranged from 11 to 101 OU/m^3 and 13 to 99 OU/m^3, respectively. Razote et al. (2007) reported the PM_{10} mass concentration generally decreased with an increase in manure moisture content.

Mitigation Mechanism:

Dust problems develop during dry weather and often occur during dusk when cattle activity begins to increase as the temperatures start to decline. Cattle that have been resting during the heat of the day become active including movement to the feed bunk, water trough and socializing. A dust inversion remains in the vicinity of the feedlot area with movement creating potential air quality standard non attainment dependent upon wind speed and direction. Increasing the moisture content of the pen surface reduces the particles that become air borne due to cattle activity.

Several abatement strategies, including manure compaction and harvesting, increased stocking density, and timing of feeding, have been proposed to mitigate PM emissions from open cattle feedlots (Auvermann et al., 2006; Auvermann and Romanillos, 2000). One of the most common practices is surface water application. In this practice, water is applied on the corral surface using an irrigation system or water trucks equipped with spray nozzles.

Sprinkler systems can be effectively used to control dust in open feedlots. There is less potential for dust events as the water applied increases. Excess water used in dust control can create anaerobic conditions in the manure pack and odor problems. Also, too dry or too wet of conditions can lead to animal health problems. Auvermann (2001) and Auvermann and Romanillos (2001) report that manure pack moisture from 25 to 40% by weight will limit both odor and dust from open feedlots. Therefore, feedlot operations must balance between applying too much or too little water to maintain optimum animal weight gain while limiting the environmental impacts of dust and odor.

Applicability:

Dust abatement utilizing water is applicable to beef cattle feedlots or dairy dry lots. Normally, dust abatement is necessary in areas with high daily evaporation such as the High Plains region. Evaporation results in earthen lot surfaces having moisture contents of less than 10 percent since rainfall and urine are evaporated. Water sprinkling systems are used to increase the surface moisture content to 25 to 35 percent to minimize the impact or PM_{10} emissions. Research suggests surface moisture contents in excess of 35 percent may lead to odor problems. Therefore, proper design and operation of the system is necessary to minimize particulate and odor emission problems.

Limitations:

Water sprinkling has been considered a best management practice for mitigating particulate matter (PM) emissions from open beef cattle feedlots; however, limited data are available on its impact on air pollutant emissions from the feedlots. Razote et al. (2007) measured the concentrations of PM_{10} downwind and upwind of a water-sprinkled commercial cattle feedlot in Kansas. PM_{10} concentrations were measured with collocated Tapered Element Oscillating Microbalances^{TM} (TEOMs), federal reference method (FRM) high-volume PM_{10} samplers, and FRM low-volume PM_{10} samplers. In addition to the PM_{10} concentration, the following parameters were monitored: (1) TSP concentration downwind and upwind of the feedlot; (2) particle size distribution downwind of the feedlot; (3) odor detection threshold (DT) upwind and downwind of the feedlot; (4) manure moisture content; (6) weather conditions; and (7) sprinkler water use. PM_{10} mass concentration also generally decreased with an increase in manure moisture content. Comparison of collocated PM_{10} samplers showed that the measured PM_{10} mass concentration was largest with the TEOM PM_{10} sampler and smallest with the low-volume PM_{10} sampler. Odor DTs, upwind and downwind of the feedlot, also varied considerably and ranged from 11 to 101 OU/m^3 and 13 to 99 OU/m^3, respectively. The operation of the water sprinkling system and manure moisture content did not seem to influence mean odor DT.

Cost:

Economists participating in the federal Air Quality Initiative have evaluated the cost per head marketed for different size feedlots using either a traveling gun or solid set sprinkler system (Amosson et al., 2006; 2007). Table 1 summarizes the results of these economic studies.

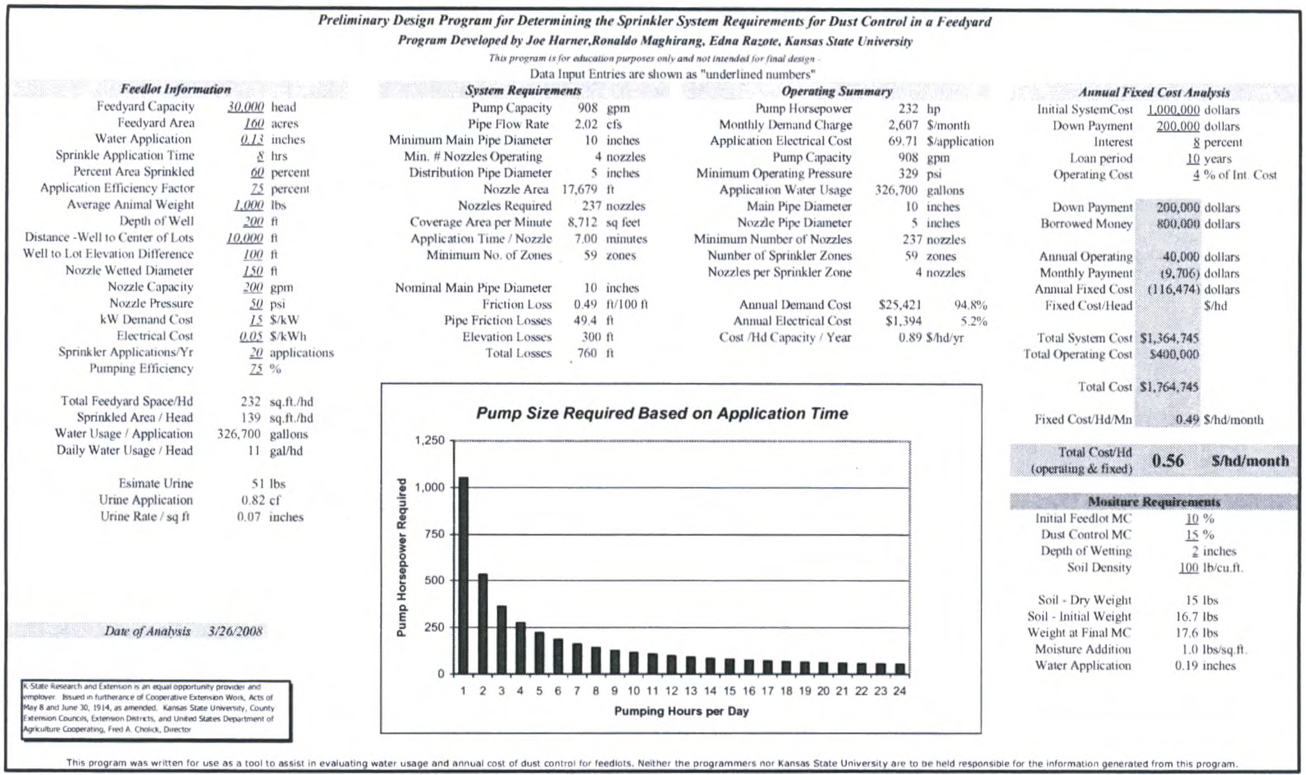
Table 1 Total annual cost per head marketed for various feedlot capacities and turnover rates. The traveling gun sprinkler system is evaluated based on a 20 year useful life and the solid set sprinkler system utilizes a 25 year useful life.

Feedlot Capacity (Head)	Turnover Rate (hd marketed / hd capacity)	Type of Sprinkler System	
		Traveling Gun[1]	Solid Set[2]
10,000	1.75	$0.95	$2.34
	2.00	$0.83	$2.05
	2.25	$0.74	$1.82
30,000	1.75	$0.79	$1.69
	2.00	$0.69	$1.48
	2.25	$0.61	$1.32
50,000	1.75	$0.78	$1.60
	2.00	$0.68	$1.40
	2.25	$0.61	$1.24

[1] Amosson et al. (2007)
[2] Amosson et al. (2006)

Implementation:

A computer model was developed to provide individual operations a preliminary estimate of water requirements and monthly cost of per head for dust abatement. Model inputs include parameters related to feedlot, water supply and location, initial system investment and electrical cost. These inputs provide information on pump capacity and horsepower, operating pressure, main and branch water line sizes, number of sprinkler zones, operational time per sprinkler zone, pumping cost and fixed monthly cost. Figure 1 provides an illustration of the input and outputs from



Preliminary Design Program for Determining the Sprinkler System Requirements for Dust Control in a Feedyard

Program Developed by Joe Harner,Ronaldo Maghirang, Edna Razote, Kansas State University

This program is for education purposes only and not intended for final design -

Data Input Entries are shown as "underlined numbers"

Feedlot Information

Feedyard Capacity	30,000	head
Feedyard Area	160	acres
Water Application	0.13	inches
Sprinkle Application Time	8	hrs
Percent Area Sprinkled	60	percent
Application Efficiency Factor	75	percent
Average Animal Weight	1,000	lbs
Depth of Well	200	ft
Distance -Well to Center of Lots	10,000	ft
Well to Lot Elevation Difference	100	ft
Nozzle Wetted Diameter	150	ft
Nozzle Capacity	200	gpm
Nozzle Pressure	50	psi
kW Demand Cost	15	$/kW
Electrical Cost	0.05	$/kWh
Sprinkler Applications/Yr	20	applications
Pumping Efficiency	75	%
Total Feedyard Space/Hd	232	sq.ft./hd
Sprinkled Area / Head	139	sq.ft./hd
Water Usage / Application	326,700	gallons
Daily Water Usage / Head	11	gal/hd
Esimate Urine	51	lbs
Urine Application	0.82	cf
Urine Rate / sq ft	0.07	inches

Date of Analysis *3/26/2008*

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System Requirements

Pump Capacity	908	gpm
Pipe Flow Rate	2.02	cfs
Minimum Main Pipe Diameter	10	inches
Min. # Nozzles Operating	4	nozzles
Distribution Pipe Diameter	5	inches
Nozzle Area	17,679	ft
Nozzles Required	237	nozzles
Coverage Area per Minute	8,712	sq feet
Application Time / Nozzle	7.00	minutes
Minimum No. of Zones	59	zones
Nominal Main Pipe Diameter	10	inches
Friction Loss	0.49	ft/100 ft
Pipe Friction Losses	49.4	ft
Elevation Losses	300	ft
Total Losses	760	ft

Operating Summary

Pump Horsepower	232	hp
Monthly Demand Charge	2,607	$/month
Application Electrical Cost	69.71	$/application
Pump Capacity	908	gpm
Minimum Operating Pressure	329	psi
Application Water Usage	326,700	gallons
Main Pipe Diameter	10	inches
Nozzle Pipe Diameter	5	inches
Minimum Number of Nozzles	237	nozzles
Number of Sprinkler Zones	59	zones
Nozzles per Sprinkler Zone	4	nozzles
Annual Demand Cost	$25,421	94.8%
Annual Electrical Cost	$1,394	5.2%
Cost /Hd Capacity / Year	0.89	$/hd/yr

Annual Fixed Cost Analysis

Initial SystemCost	1,000,000	dollars
Down Payment	200,000	dollars
Interest	8	percent
Loan period	10	years
Operating Cost	4	% of Int. Cost
Down Payment	200,000	dollars
Borrowed Money	800,000	dollars
Annual Operating	40,000	dollars
Monthly Payment	(9,706)	dollars
Annual Fixed Cost	(116,474)	dollars
Fixed Cost/Head		$/hd
Total System Cost	$1,364,745	
Total Operating Cost	$400,000	
Total Cost	$1,764,745	
Fixed Cost/Hd/Mn	0.49	$/hd/month
Total Cost/Hd (operating & fixed)	**0.56**	**$/hd/month**

Mositure Requirements

Initial Feedlot MC	10	%
Dust Control MC	15	%
Depth of Wetting	2	inches
Soil Density	100	lb/cu.ft.
Soil - Dry Weight	15	lbs
Soil - Initial Weight	16.7	lbs
Weight at Final MC	17.6	lbs
Moisture Addition	1.0	lbs/sq.ft.
Water Application	0.19	inches

This program was written for use as a tool to assist in evaluating water usage and annual cost of dust control for feedlots. Neither the programmers nor Kansas State University are to be held responsible for the information generated from this program.

Figure 1 Computer screen of the spreadsheet model used to provide preliminary design information and estimate the annual cost for controlling dust with a sprinkler set.

The computer model. A single screen format was used to enable individuals to view the impact of input changes. Also, a graph is used to illustrate the impact of pumping time on pump horsepower requirements. Optimum dust abatement is obtained with water applications two to three hours prior to dusk to minimize the impact of evaporation and drying of the surface prior to cattle activity. The graph shows the impact on pump horsepower requirements as the application rate period is reduced from 24 hours to 1 hour.

A Kansas cooperator involved with air quality monitoring project recorded daily water meter readings of a well supplying a sprinkler system for feedlot dust abatement. The average water usage was 41.6 liters per day per head (l/d/hd). The solid set sprinkler system operated 142 days during 2007. The peak application rate during a single 24 hour period was 91.9 l/d/hd. Twenty four percent of the applications were 60.5 l/d/hd or greater and 33 percent of the applications were less than 25.3 l/d/hd. Table 2 shows the estimated daily water usage based on feedlot stocking density and the initial and final surface moisture content the model predicted water use requirements. The daily water usage per head ranges from 76 to 438 l/d/hd and well capacity ranges from 105 to 425 liters per second (l/s). This table was based on dust abatement for a 20,000 head feedlot and assumes the surface is wetted a depth of one inch and the total feedlot surface area is wetted within an 8 hour period. The water usage exceeds the rates application rates reported by the cooperating Kansas feedlot.

Table 3 shows the impact of stock density when water is limited to 41.6 l/d/head based on data collected at the Kansas feedlot. The surface moisture content does not reach the desired moisture content of 25 % regardless of the stocking density. This may explain why Razote et al. (2007) reported inclusive evidence on the benefits of sprinkling feedlots based on the field observations at a single feedlot.

Table 2 Estimate of daily water usage and well capacity as a function of initial and final surface moisture contents and stocking density.

Initial Surface Moisture Content (%)	Final Surface Moisture Content (%)	Feedlot Stocking Density (square meters per head)					
		9.3		18.6		27.9	
		Water Usage (l/d/hd)	Well Capacity (l/s)	Water Usage (l/d/hd)	Well Capacity (l/s)	Water Usage (l/d/hd)	Well Capacity (l/s)
10	25	113	100	151	140	227	210
	35	219	200	295	270	438	410
15	25	76	70	98	90	148	140
	35	174	160	234	220	348	320

Table 3 Impact of limiting daily water usage to 41.6 l/d/hd on final surface moisture content as a function of stocking density

	Feedlot Stocking Density (square meters per head)		
	9.3	18.6	27.9
Water Application Rate (mm/square meter)	0.31	0.19	0.14
Estimate of Final Surface Moisture Content assuming 1" depth wetting zone and Initial moisture content of 10 %	16.5%	14.5%	13%
Pump Size (kW)	83	103	114
Well Capacity (l/s)	43	36	39

Technology Summary:

The beef cattle industry has been faced with environmental concerns, including air quality impairment within and downwind of the beef cattle feedlots. Particulate matter (PM) emission is a major factor that impacts air quality from the feedlot and poses health concerns to humans and animals alike. In general, the major source of PM emission from a cattle feedlot is the pen surface. Particulate matter is emitted when cattle hooves trample on the dry, uncompacted layer of manure and soil. Other sources of PM emission are unpaved roads, hay grinding, grain handling and feed processing. Sprinkler systems can be effectively used to control dust in open feedlots. There is less potential for dust events as the amount of water applied increases. Excess water used in dust control can create anaerobic conditions in the manure pack creating odor problems. Studies suggest the manure pack moisture from 25 to 35% by weight will limit both odor and dust from open feedlots. Economic studies indicate the cost per marketed head per year ranges from $0.60 to $2.40 depending on feedlot turnover and type of sprinkler systems installed. A computer has been developed to help evaluated the water requirements necessary to obtain the 25- to 35 % moisture on the feedlot surface and well capacity. The model also provides a indicator of monthly cost per feedlot head capacity based on economic inputs.

Additional Resources:

More information is available at The Air Quality: Odor, Dust and Gaseous Emissions from Concentrated Animal Feeding Operations (CAFOs) in the Southern Plains website. Their web address is http://cafoaq.tamu.edu/.

Acknowledgments:

This study was supported by the USDA-CSREES Special Research Grant "Air Quality: Odor, Dust and Gaseous Emissions from Concentrated Animal Feeding Operations in the Southern Great Plains," through the Texas Agricultural Experiment Station of the Texas A&M University System and by the Kansas Agricultural Experiment Station.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
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Reducing H_2S, NH_3, PM, & Odor Emissions from Deep-pit Pig Finishing Facilities by Managing Pit Ventilation

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Bioproducts & Biosystems Engineering, University of Minnesota

Species: Swine (maybe Dairy and Poultry)
Use Area: Animal Housing
Technology Category: Management
Air Mitigated Pollutants: Odor, Hydrogen Sulfide, Ammonia, Particulate $Matter_{10}$ (under 10 microns)

Description:

Indoor air quality and emissions of hazardous gases such as ammonia (NH_3) and hydrogen sulfide (H_2S) plus particulate matter under 10 microns in diameter (PM_{10}) and odor are a concern in pig facilities where manure is stored in a deep pit (typically 2.5 m (8 ft) deep) under the barn's floor that is only separated from the animal and worker areas by concrete slats. Deep-pit, pig buildings are the standard housing systems for Midwestern U.S. pig nursery and grow-finish facilities and even for sow facilities in states like Minnesota that prohibit earthen manure storage basin for swine. The MidWest Plan Service (MWPS-32, 1990) recommends that "at least the cold weather rate but no more than the mild weather rate of a barn's ventilation airflow" be provided by pit fans. Unfortunately, the MWPS pit fan recommendation for deep pitted barn is not based on any known research results but rather on what seems to be a logical assumption that air exhausted from the pit area would remove more of the airborne contaminants (gases and odors especially) from the building and subsequently improve the indoor air quality in the barn compared to air removed by wall mounted fans.

A recent study (Jacobson, et al. 2005) determined that a large majority (75 to 80 %) of the total NH_3 and H_2S emissions from a 2000-head tunnel-ventilated deep-pit pig-finishing barn for 45 days during August and September 2004 were emitted from the pit exhaust stream even though only 20 to 30 % of the total barn's ventilation air was being provided by pit fans. This information allows producers with deep-pit facilities to strategically utilize catch and treat emission control technologies, such as biofilters, ONLY on pit fans airstreams that would result in large reductions (>50%) in the emissions of hazardous gases, odor, and particulate matter by treating only a small portion of the total ventilation air (figure 1). Another follow up study (Jacobson, et al. 2007) found that emissions of certain pollutants, may be reduced slightly (10 to 20%) by simply eliminating pit fans altogether for a deep-pitted pig building.

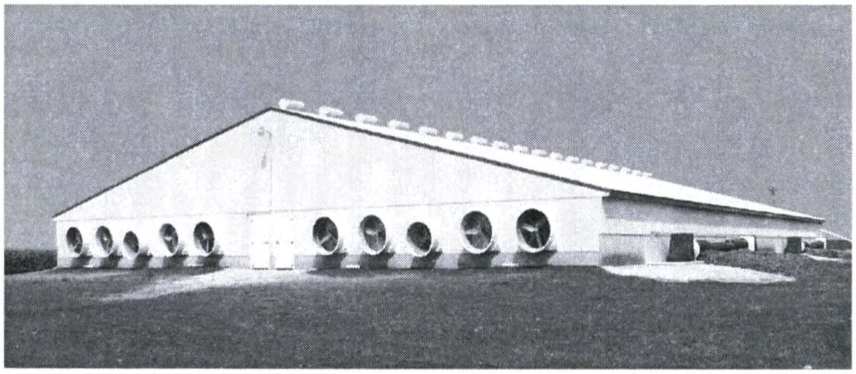

Figure 1. 2400 head, deep-pit, pig finishing barn with biofilter treated air from pit fans

Mitigation Mechanism:

The distribution or partitioning of the emission levels for certain gases, odor, and particulate matter between the pit and wall fan airstreams in deep-pit pig facilities for various pit ventilation rates is not well understood or predictable. Presently, the only viable method of determining this information is by monitoring existing pig facilities using robust instrumentation for both the measurement of pollutant concentrations as well as the airflow rates in the buildings to calculate emission rates. Mathematical modeling (Janni, et al. 2008) of this process is under development and when these models are refined and validated, they will provide a much less intensive method of determining the emission partitioning for important airborne pollutants for deep-pitted buildings.

Applicability:

Based on recent research, pit fans exhaust air, from deep pitted swine finishing barns in the Midwest, emit a disproportionate amount of ammonia (NH_3), hydrogen sulfide (H_2S), particulate matter under 10 microns in diameter (PM_{10}), and odor compared to the air emitted by wall fans. For a typical 1200 head pig finishing room, with pit fan(s) capacity of 35 m^3/hr-pig (≈ 20 cfm/pig), which is approximately 20% of the total barn's ventilation rate, the pit exhaust airstream contains a majority (> 50 %) of the total NH_3,H_2S, PM_{10} and odor emissions emitted from the barn (figure 2). Thus, if a pork producer needs to reduce emissions, it is important to know that some type of catch and treat technology (such as biofilters) only needs to be applied to the pit fans (20 % of total airflow) to achieve a sizeable reduction (50% or more) in a particular pollutant.

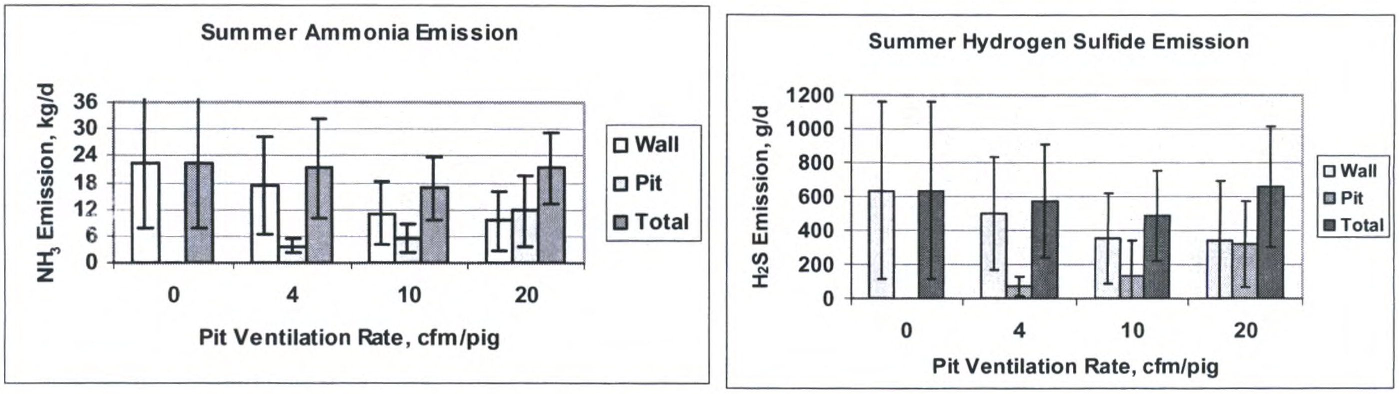

Figure 2. Summer NH_3 and H_2S emissions from one room of a 2400 head double wide, deep-pitted, tunnel ventilated pig finishing building with pit ventilation rates of 0, 4, 10, and 20 cfm/pig.

As the percentage of pit to wall fan capacity is reduced, so does the percentage of gas and odor emissions from the pit fan's airstream. However, if no pit fans are used to ventilate a deep pit pig finishing barn, only slight reductions (0 to 20%) in the total barn's NH_3, H_2S, PM_{10}, and odor emissions are found. As indicated by NH_3 and H_2S concentrations in the middle of the barn (figure 3), the indoor air quality is not appreciably affected by the presence of pit fans, assuming the ventilation system is well designed and there is adequate fan capacity in the walls.

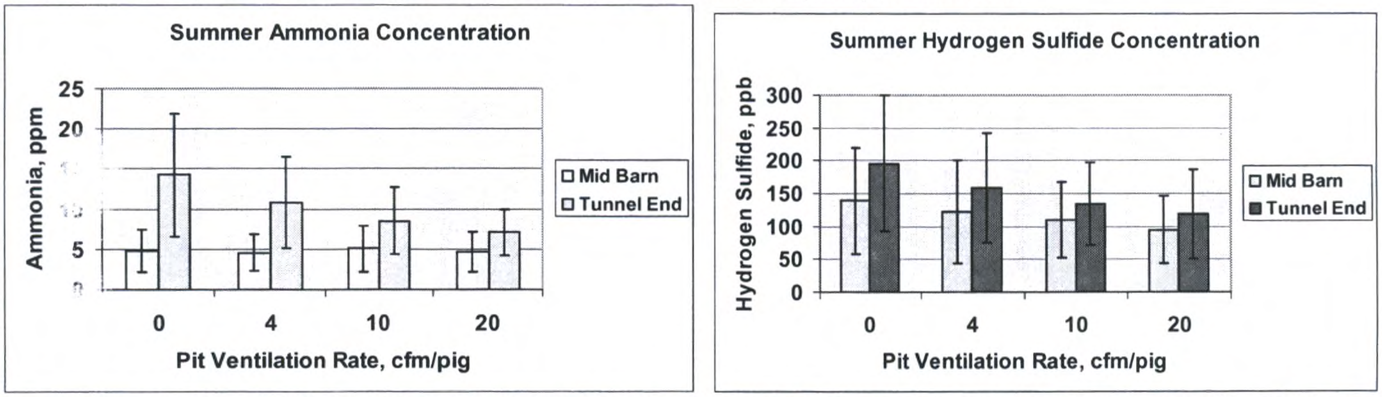

Figure 3. Summer NH_3 and H_2S conc. from one room of a 2400 head double wide, deep-pitted, tunnel ventilated pig finishing building with pit ventilation rates of 0, 4, 10, and 20 cfm/pig.

Limitations:

The selection and management of pit fan ventilation for deep-pit pig buildings has only been investigated for pig finishing units. Similar results are anticipated for other swine production stages (farrowing, gestation, and nursery) that are housed in deep-pit barns; however the estimated emission reduction potential for these facilities may be different than reported above for finishing barns. Only the two common hazardous gases (NH_3 and H_2S), odor, and PM_{10} responses have been documented in pig finishing buildings. Greenhouse gases (CO_2, CH_4, N_2O, and others) will be of interest in the future.

Other animal species such as dairy and poultry may be housed in buildings that have deep-pit manure storage directly under the animal housing area. Again, knowing the distribution of the emissions coming from the "pit" air stream and the "wall" air stream from these housing systems will allow producers to optimize emission control technology use so emissions can be maximized.

Cost:

There is no additional cost of this "technology" since a ventilation system is needed in deep-pit pig buildings anyway. There actually may be a cost saving if producers decided to install no or only limited (1 or 2) pit fans instead of the standard number for the industry which is approximately 20% of the total barn's ventilation system, that translate to 4 fans in the typical 1200 head finishing room. The cost savings is realized since the installation of pit fans is typically more expensive than wall fans plus pit fans have higher maintenance and more frequent replacement costs.

Implementation:

The implementation of this technology is simply applying the knowledge of the disproportionate emissions of important gases, odor, and particulate matter through the pit fan airstreams compared to the emissions of these parameters via the wall fan airstreams. This can be applied to both existing and new facilities, although when retrofitting an existing buildings some switching of pit to wall fans may be necessary to optimize the use of certain control technologies and/or to obtain the necessary emission reduction level desired.

Technology Summary:

A large portion of the NH_3, H_2S, PM_{10}, and odor emissions, from deep-pit pig finishing barns, were found in the pit fan exhaust air compared to air exhausted by the wall fans. This knowledge is important for producers that want or need to reduce a pig finishing barn's NH_3, H_2S, PM_{10} and odor emissions, since there would be a benefit to treating only the pit fan exhaust air with an emission control technology rather than all of the exhaust air (wall and pit). The phenomenal of a majority of the barn's airborne pollutants being emitted by pit fans, may also be true for other swine production phases or for even other species (dairy and poultry) housed in deep pit facilities. This would mean that emission reductions of >50 % for certain pollutants are potentially possible when emission control technologies like biofilters are strategically placed on large emitting pit fan sources in deep-pit buildings. If only small reductions (<20%) of certain pollutants are needed, this maybe accomplished by the elimination of pit fans altogether.

Additional Resources:

BAEU-18 Biofilter Design Information, available at http://www.manure.umn.edu/assets/baeu18.pdf.

Acknowledgments:

The authors would like to thank the National Pork Board for financially supporting the research from which these recommendations were made.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
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Effects of Waste Management Techniques to Reduce Dairy Emissions from Freestall Housing

M. Calvo, K. Stackhouse, Y. Zhao, Y. Pan, T. Armitage, and F.M. Mitloehner
University of California, Davis

Species: Dairy Cows
Use Area: Animal Housing
Technology Category: Management
Air Mitigated Pollutants: Volatile Organic Compounds, Methanol and Ethanol

Description:

Commercial dairies are a source of air pollutants and are increasingly regulated at the federal, state, and regional level. Current regulatory estimates state that dairies produce more smog-forming volatile organic compounds (VOCs) than passenger vehicles; however, there is little data on VOC emissions emitted from dairies. Initial research conducted by Rabaud et al. (2003) identified 35 VOCs from a small California dairy and suggested that alcohols were the main compound group, which was confirmed through our investigations. However, due to the complex sources of air emissions from dairies, additional research is needed to fully quantify VOC and GHG sources and to develop effective control strategies (ARB, 2006).

Dairies have multiple emission sources, including freestall barns, feeding surfaces, silage piles, fresh waste, and manure storage ponds (EPA, 2007). Recent dairy emission research in our lab has identified alcohols (methanol and ethanol) as the major VOC group originating from silage and fresh waste (Shaw et al., 2007; Sun et al., 2008). Enhancing industry typical freestall waste management techniques such as flushing and scraping, may provide an effective yet low cost VOC emissions mitigation technique. Large commercial California dairies typically house high producing lactating cows in freestall barns. Freestall barn waste is either removed by flushing with recycled lagoon water or by scraping using a waterless method and later left to dry, to be used as bedding material or land applied as fertilizer. Many VOCs (e.g., the alcohols methanol, MeOH, and ethanol, EtOH), are produced by microbes during anaerobic fermentation in the cow's rumen. Similar microbial strains are also present in fresh waste, where they continue to ferment carbohydrates. The objective of the present mitigation technique is to improve typical freestall waste removal mitigation strategies for VOC emissions from dairies.

Mitigation Mechanism:

The flushing system is typically found on modern dairies and requires a system that pumps recycled lagoon water through the freestall barn where it collects fresh waste that is then transported back into the lagoon (EPA, 2007). Lab bench studies in our laboratory have shown that alcohols (MeOH and EtOH), which are known to be water-soluble, are effectively trapped in flush water and further downstream (i.e. in the lagoon) they are decomposed to CO_2 and CH_4. Thus, the water solubility of the alcohols may explain the great reductions that we have seen in studies that compare flushing with scraping systems. Scraping requires the use of scraping equipment (such as tractors with scraping blades) to remove the manure into waste storage facilities (EPA, 2007). Since scraping can leave a thin slurry film behind, there is still the potential for alcohols to be transferred into the atmosphere from the residual slurry film.

Applicability:

Large commercial California dairies typically house high producing lactating cows in freestall barns. These barns have a concrete ground, which provide the best means for removing large amounts of waste, whether by scraping or flushing. Our research has shown that flushing is more effective than scraping in reducing MeOH and EtOH emissions from barns. Flushing three times daily versus scraping three times daily yields an emission reduction efficiency of 50% for both MeOH and EtOH. Furthermore, flushing frequency by itself significantly reduces emissions. A comparison of 3 times versus 6 times flushing daily showed decreased emissions by 79% for MeOH and 63% for EtOH.

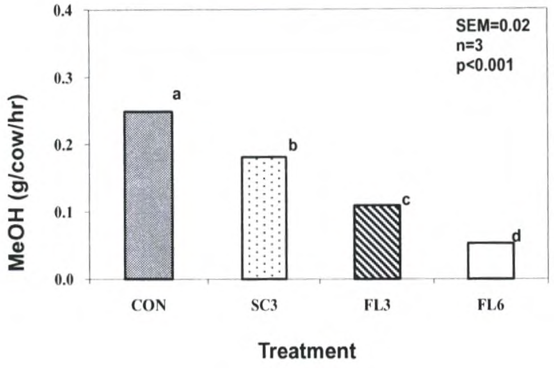

Figure 1. Effects of freestall waste management techniques on methanol emissions. (CON-Control; SC3-Scraping 3XDay; FL3-Flush 3XDay; FL6- Flush 6XDay)

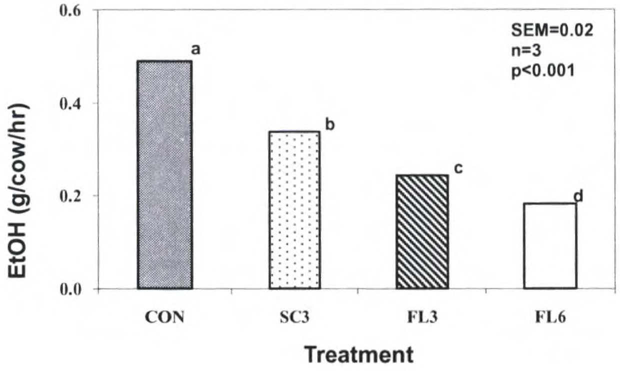

Figure 2. Effects of Freestall waste management techniques on ethanol emissions. (CON-Control; SC3-Scraping 3XDay; FL3-Flush 3XDay; FL6- Flush 6XDay)

Limitations:

Scraping leaves a thin film of residual waste on the concrete freestall floor. This film has the potential for alcohols to be transferred into the air.

Cost:

There is no cost associated with increasing the flushing frequency of a liquid manure handling system. Essentially, flushing frequency is increased, while the amount of water used for each flush is decreased. Since the water used to flush barns is recycled water from the lagoons, there is no cost to re-circulate lagoon water through the barn alleys.

Implementation:

Flush dairies can increase flushing intervals by adjusting the valves.

Technology Summary:

Typical dairy freestall waste management includes flushing and/or scraping. Enhancing waste management may provide a large impact on dairy VOC emissions (MeOH and EtOH) at a cost effective rate. Flushing versus scraping is approximately twice as effective in reducing VOC emissions under freestall conditions. More frequent flushing of dairy waste leads to further reduction of VOC emissions.

Additional Resources:

Air Resources Board Agriculture/District activities: http://www.arb.ca.gov/ag/districtact.htm.

Acknowledgments:

The project was supported by USDA CSREES.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
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Dust and Ammonia Control in Poultry Production Facilities Using an Electrostatic Space Charge System

C.W. Ritz[1], B.W. Mitchell[2], B.D. Fairchild[1], M. Czarick[1], and J.W. Worley[1]
University of Georgia[1], USDA Agricultural Research Service[2]

Species:	Poultry
Use Area:	Animal Housing
Technology Category:	Electrostatic Space Change
Air Mitigated Pollutants:	Particulate Matter and Ammonia

Description:

Air quality within poultry production housing has been a major concern for years, particularly with regard to poultry health. Environmental concerns and nuisance issues related to agricultural air emissions are now affecting all aspects of animal agriculture. Dust or Particulate Matter (PM) is a component of air emissions that may play a role in the transport of gaseous and odorous compounds. Dust concentrations in poultry houses have been reported to vary from 0.02 to 81.33 mg/m^3 for inhalable dust and from 0.01 to 6.5 mg/m^3 for respirable dust (Ellen et al., 2002). Sources of dust in poultry houses include feed, down feathers, excrement, microorganisms, and crystalline urine (Aarnink et al., 1999). Factors that affect dust levels in poultry houses include animal activity, animal density, and moisture conditions. Dust can contain large numbers of microorganisms that could have potential impact on human and bird health.

Reducing airborne dust in enclosed animal housing has been shown to result in corresponding reductions in airborne bacteria, ammonia, and odor. Studies have shown that reducing airborne dust levels by 50 percent can reduce airborne bacteria by 100 fold or more (Madelin and Wathes, 1988; Carpenter et al., 1986). The search for strategies to reduce particulate matter and ammonia emissions from animal housing has led to considerable interest in the poultry industry for practical systems to reduce these air emissions.

Several approaches can be used to reduce dust concentration within animal housing. These include the addition of fat to the feed, fogging with water and oil-based sprays, ionization, electrostatic filtration, vacuum cleaning, wet scrubbers, and purge ventilation. Reductions reported with these approaches ranged from 15 percent for weekly washing of pigs and floors, to 76 percent with a rapeseed oil spray (CIGR, 1994). Reports of ionizer efficiency have ranged from 31 percent (Czarick et al., 1985) to 92 percent (Mitchell et al., 2002).

Dust in broiler houses originates from the litter base. Bedding type, humidity, and temperature affect the dust concentration. High moisture levels in the air facilitate the absorption of ammonia into dust particles and the inhalation of the dust particles containing ammonia can cause damage to the respiratory tract (Kristensen and Wathes, 2000). Ammonia in broiler houses originates from the litter base. Bedding type, litter management, humidity, pH, and temperature affect ammonia concentration and release. For broiler house ammonia, reduction of in-house aerial concentrations has been largely accomplished through ventilation. Another trend in the industry is less-frequent, complete-house, clean-out resulting in birds being grown on built-up litter. The manure cake is removed between flocks and the remaining litter is top-dressed with new bedding material. The combination of these trends can be detrimental to air quality in broiler houses if dust and ammonia levels are not managed, particularly during the brooding phase.

An Electrostatic Space Charge System (ESCS) described by Mitchell and Stone, 2000, has been shown to significantly improve air quality by reducing airborne pathogens and disease transmission in poultry. The principle behind the ESCS is to transfer a strong negative electrostatic charge to airborne dust particles within an enclosed space. The negatively charged particles will then precipitate out of the air as they are attracted to grounded surfaces. Nitrogen compounds attached to the dust will also precipitate out with the dust.

Based on the work be Mitchell and others, an ESCS was designed to determine whether a practical system can be developed for operation in a commercial broiler production house. The system was evaluated for effectiveness of this technology for improving air quality in the house through reductions in concentrations of dust and ammonia.

Mitigation Mechanism:

A custom-made ESCS system was designed and installed in a 500 ft x 40 ft tunnel ventilated commercial broiler house. The system consisted of four rows of in-line, negative-air ionization units with two 200 ft rows on each side of the house in the brood end and two 200 ft rows in the grow-out end, as shown in FIGURE 1. Separate high voltage (-30 kVdc, 2 mA) power supplies were used to supply -25 kVdc to the ion generators in each half of the house. The high voltage power supply for the ESCS was current limited to a safe level of 2.0 mA. The in-line generators consisted of a conductive tube with electrodes at one-in. intervals and attached to a grounded one-in. diameter black iron pipe. The iron pipe was located 3 in. above the discharge points to provide a close proximity ground plane and to increase the negative ion output. The ESCS was positioned to a height of seven ft above the litter which was sufficiently high to walk under but low enough to concentrate the charge near the birds where dust is generated. A broiler house adjacent, and essentially identical, to the treatment house was instrumented for airborne dust and ammonia monitoring but operated without ionization. Each house was initially bedded with pine shavings and the caked litter material around the feeders and drinkers was removed between each flock followed by a thin top-dressing of new shavings.

Dust concentrations were measured with a TSI DustTrak (TSI), a laser-based instrument with a particulate range of 0.001 to 100 mg/m^3. Aerial ammonia was measured with a Draeger Polytron I (Draeger) electrochemical sensor with a sensitivity range from 0 to 100 ppm. Data were collected for three sampling periods during each of seven flocks during the first, third, and fifth weeks of production. Air samples were collected continuously for approximately five d during each period. Sampling frequency was once every 15 minutes for dust and once every minute for ammonia. Mean concentrations were calculated for each sampling period. Due to the large amount of collected data during each sampling period, hourly means were generated to calculate the sampling period mean.

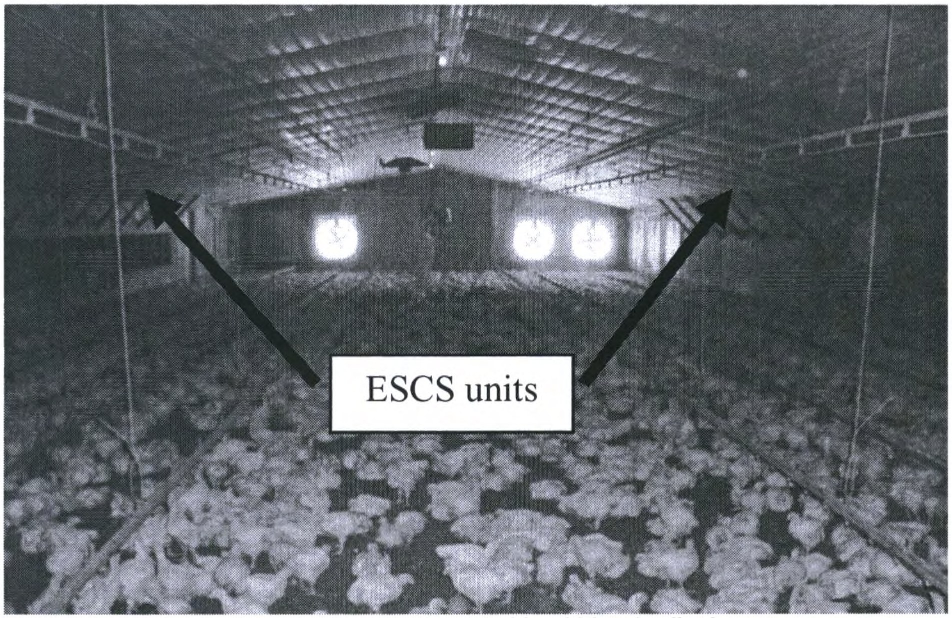

FIGURE 1. Electrostatic space charge unit assembly within a broiler house.

Applicability:

Results from this study suggest that an ESCS can be effective in reducing poultry house dust and ammonia concentrations in floor-raised meat-bird housing where bedding material is utilized. The system will likely require considerable modification for use in high rise layer facilities or used as an emissions control device exterior to the animal housing. However, the principles of the technology remain as follows: to produce an electrostatic space charge that will reduce aerial dust and ammonia concentrations.

Limitations:

The incidences of static discharge to workers were minimal. The intensity of a discharge from direct contact with an ESCS ionizer was similar to touching a spark plug wire on a gasoline engine.

Cost:

The cost of materials and installation of the experimental ESCS unit was approximately $4,000. Power consumption of the entire system was less than 100 watts during operation. It is reasonable to assume that a commercially available product would have a reduced capital outlay and quicker return on investment than the experimental prototype used within this study.

Implementation:

Figure 2 is an example sampling period showing the reduction of dust concentrations as influenced by the ECSC within the broiler house. After seven flocks were studied with the ESCS in place, the data indicate the ESCS significantly reduced airborne dust by an average of 43 percent and reduced ammonia by an average of 13 percent (Table 1).

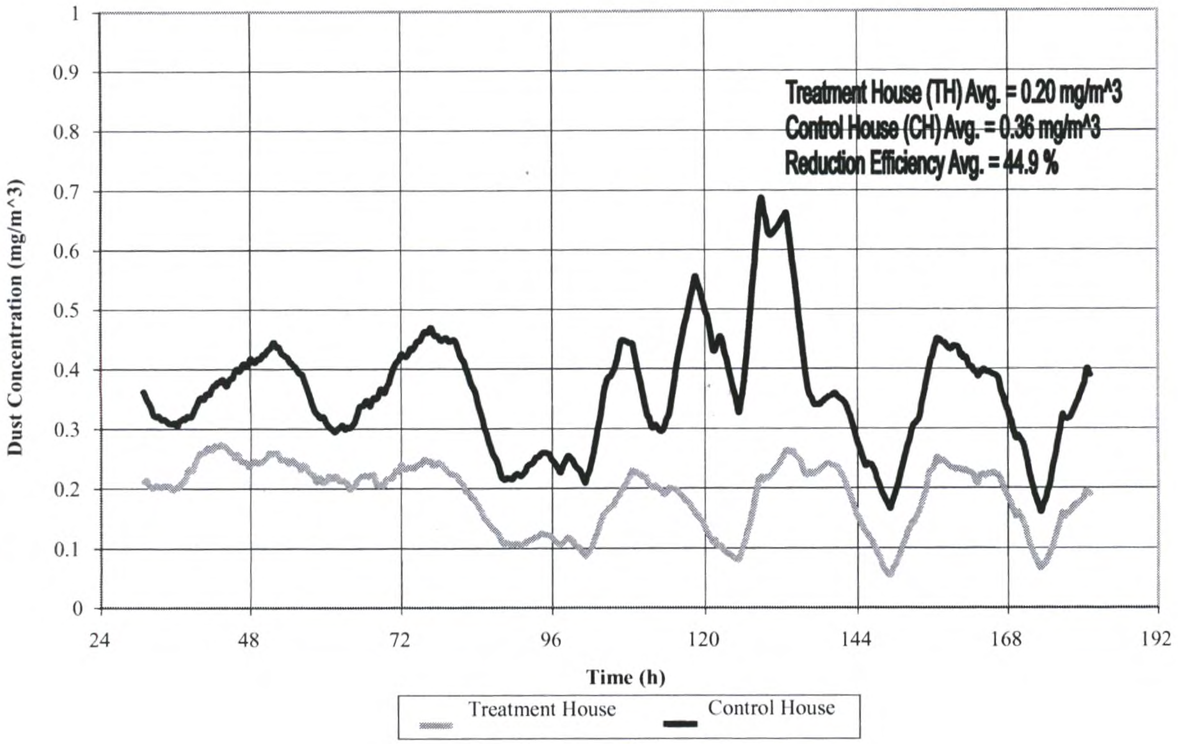

FIGURE 2. Example sampling period showing the reduction in dust concentrations within the treated and non-treated broiler houses.

TABLE 1. Efficiency of electrostatic space charge system (ESCS) for reduction of broiler house dust and ammonia concentrations.

Flock	Period	Dust Concentration Mean (mg/m^3)			NH_3 Concentration Mean (ppm)		
		Control	Treatment	Reduction %	Control	Treatment	Reduction %
1	Jan-Feb	1.13	0.60	46.9	44	38	13.6
2	Mar-Apr	0.48	0.27	43.7	54	46	14.8
3	May-Jun	0.14	0.09	35.7	24	19	20.8
4	Jun-Jul	0.49	0.36	26.5	20	17	15.0
5	Aug-Sept	0.47	0.23	51.1	12	11	8.3
6	Oct-Nov	0.63	0.38	39.7	31	27	12.9
7	Nov-Dec	1.10	0.44	60.0	51	47	7.8
Mean ± SEM		0.63 ± 0.030	0.34 ± 0.014	43.4 ± 0.913	34 ± 1.369	29 ± 1.187	13.3 ± 4.086

Technology Summary:

Electrostatic Space Charge technology can be used to mitigate dust and ammonia emissions within poultry production facilities and may have application as an emissions control strategy. Research suggests that reduction in dust can exceed 40 percent while ammonia concentrations can be reduced 10-15 percent. The effectiveness of the system is increased with higher dust concentrations. Reducing ammonia concentrations inside poultry houses may require separate control strategies than those designed for dust reduction in order to ameliorate poor air quality and emissions attributed to ammonia. Cost of the system for an individual poultry house will depend on mass production of the needed materials, though the overall cost will likely be lower than the $4,000 needed for the experimental unit described in this study. Electrostatic fields have not been shown to produce adverse health effects in animals or humans. No differences in bird activity were observed in the form of decreased water consumption or increased mortality and no adverse effects of the continuous charge were observed in the form of stray voltage or static discharge at the feeder and water lines.

Additional Resources:

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Acknowledgments:

Project support was provided by the U.S. Poultry & Egg Association.

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As published in the proceedings of:
Mitigating Air Emissions from Animal Feeding Operations Conference
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
Iowa Farm Bureau Federation
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Ozone Application for Mitigating Ammonia Emission from Poultry Manure: Field and Laboratory Evaluations

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Department of Biological and Agricultural Engineering[1], Department of Poultry Science[2]
North Carolina State University

Species: Poultry (Broiler and Layer)
Use Area: Animal Housing
Technology Category: Ozanation
Air Mitigated Pollutants: Ammonia

Description:

Ammonia, as a harmful gas in broiler chicken housing, is known to significantly compromise poultry welfare (Dawkins et al., 2004). Reduction of ammonia level inside poultry houses is not only important to gain compliance with current air quality regulations and laws, but also to increase birds' live performance. Among various mitigation technologies for animal house ammonia control, house ozonation is the most controversial technique. Reported results in the literature with regard to ozonation application for air emission control are somewhat contradictory (Keener et al., 1999; Yokoyama and Masten, 2000; Elenbaas-Thomas et al., 2005). Work by Keener et. al (1999) indicates that ozone (O_3) treatment at concentrations levels between 0 and 0.15 ppm removed 58% of ammonia and 60% of dust mass in a swine building, whereas Elenbaas-Thomas et al. (2005) reported that room ozonation in a swine building at a maximum O_3 concentration of 0.1 ppm did not result in any statistically significant reduction in dust mass concentrations, odor concentrations, sulfur compound concentrations, and bacteria counts. Moreover, significantly higher ammonia concentrations were observed in the ozone treated room as compared with the room without ozone treatment in the study reported by Elenbaas-Thomas and collaborators. Schwean et al. (2001) also evaluated the effect of adding ozone (target level of 0.05 ppm) to rooms housing broilers. The authors concluded that the application of this gas in a commercial broiler unit is unacceptable at the dosage studied due to increments in mortality and reduced body gain and feed intake. However, a significant improvement in the mortality corrected gain to feed ratio was noted in the O_3-treated birds (0.553 *vs* 0.535). This study was conducted in only three rooms of five replicate pens, each containing 110 birds. Housing of this type plus other factors can affect mortality, especially in small sample sizes as used in this study. The ammonia levels were measured only at specific days (15, 20, 28, 32, and 38 d), and the addition of O_3 caused a near-significant reduction in ammonia levels at 38 d (12.7 *vs* 25.7 ppm) and total aerobe populations at 19 d (142 *vs* 225 colonies/plate).

The controversy over application of ozonation technique also comes from ozone's health effect. Although as a powerful oxidizing agent ozone at high concentration level may have potential to remove ammonia through chemical reaction, ground-level ozone has been defined as a criteria pollutant by the US Environmental Protection Agency under Clean Air Act (EPA, 1996) due to its harmful effects on the respiratory systems of human beings and animals. The current health standards/limits for ozone exposure are 0.1 ppm for an 8-hour, time-weighted average exposure by the Occupational Safety & Health Administration (OSHA, 1998), 0.05 ppm for continuous exposure by the Food and Drug Administration (FDA, 1998), and 0.08 ppm maximum 8-hour outdoor concentration by EPA (1996). According to EPA's report (1998), it may take ozone concentrations 5-10 times higher than these standards before ozone could decontaminate the air. Ozone is not effective at removing air contaminates under the public health standard limits (EPA, 1998).

This reported study aimed to evaluate the effectiveness of in-house ozonation under safety limits for mitigating ammonia emission from poultry manure on the farm scale as well as in the laboratory controlled condition. In addition, bird performance under continuous exposure to ozone was also evaluated.

Mitigation Mechanism:

The fundamental mechanism used by the ozonation technique for ammonia mitigation is built upon an assumption that due to its strong oxidizing property, ozone may remove ammonia from the air through chemical reaction. This chemical reaction is described by the following equation (Wikipedia, 2008):

$$2NH_3 + 4O_3 \longrightarrow NH_4NO_3 + 4O_2 + H_2O \qquad [1]$$

Contrary to the claim of this removal mechanism, some scientists reported that the reaction process of ozone with many indoor chemical contaminants may take months or years (Salls, 1927; Shaughnessy et al., 1994; Esswein and Boeniger, 1994; Boeniger, 1995). Hoigne also reported that direct oxidation of NH_3 by ozone in the aqueous phase is very slow. Based upon comprehensive review of the sound science, only peer-reviewed scientifically supported findings and conclusions, EPA (1998) has claimed that ozone does not react at all with indoor air contaminant chemicals for all practical purposes.

While the reaction in equation 1 may only hold at the ozone level that exceeds current public health standard limits, this reaction will produce another criteria pollutant, ammonium nitrate, which is also known as a secondary aerosol. The concentration of ozone used depends on the characteristics of the air to be treated, and as a matter of fact, there are large differences between commercial and research houses. The half-life of ozone is 2.5 to 7 minutes, but in a cool, sterile environment, its half-life can be extended to 60 minutes (Keener et al., 1999).

Applicability:

The room ozonation technique aimed to mitigate in-house ammonia concentration in poultry production systems. Our field and laboratory studies indicate that this technique is not effective at removing ammonia inside broiler houses. Due to ozone's potential adverse impact on the health of workers and birds, and its effectiveness, the application of this technique is subject to debate. It is important to observe closely the effects of this technology, since ozonation is already in use in several broiler chicken farms in the Southeast region of the United States.

Limitations:

Results (figures 1 - 4) from a field evaluation (on a commercial broiler farm) and a laboratory study indicate the following limitations of using this technique:

- In-house ozonation at the threshold limits for public health standards is not effective at mitigating ammonia concentration inside the broiler houses
- Ozone treatment had positive effects on broiler performance in two broiler flocks and adverse impact in two flocks
- Ozone treatment may cause higher level of fine / ultra fine particles / aerosols.

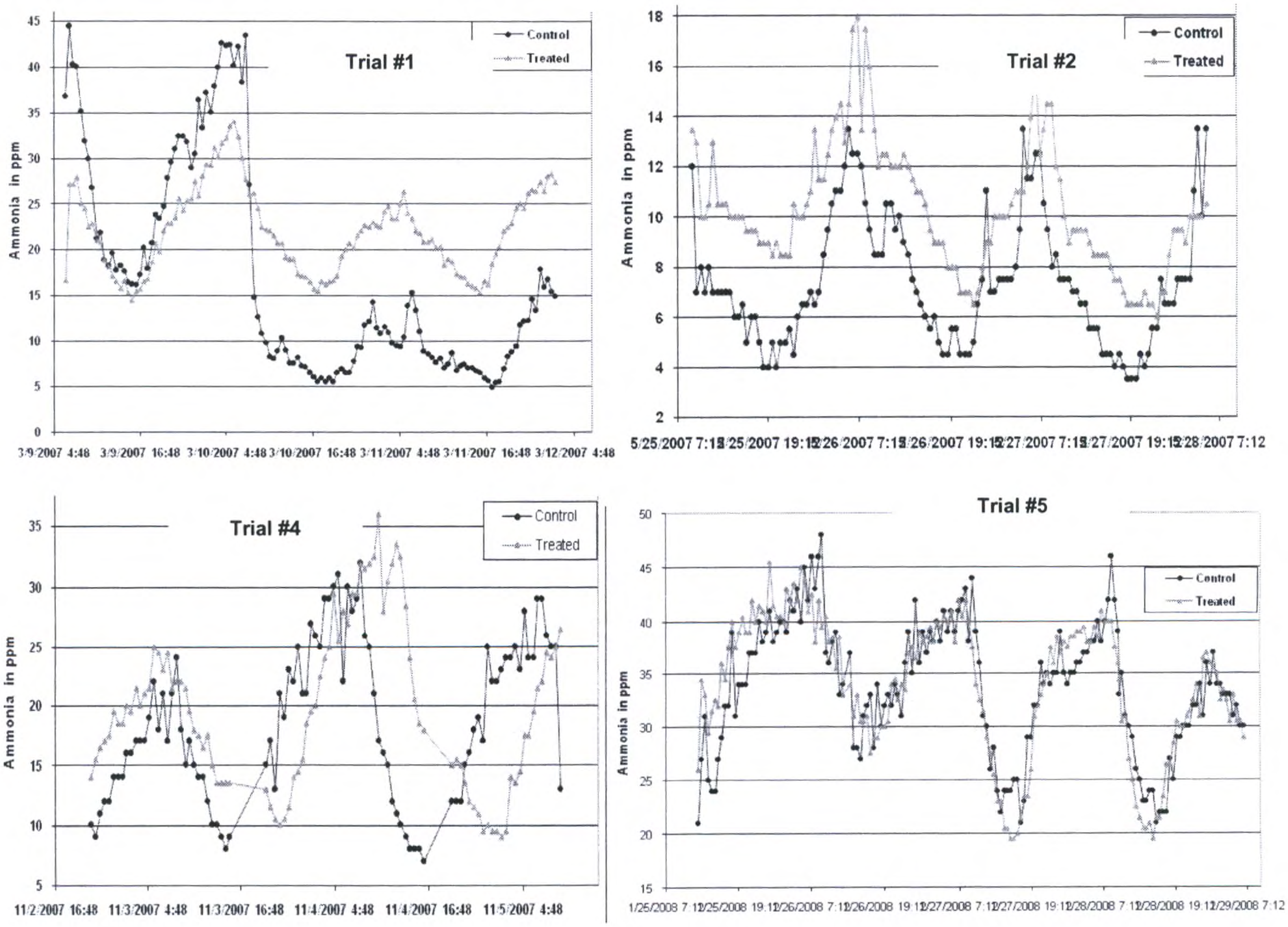

Figure 1. An example of comparison of in-house ammonia concentration between control and treated houses (Field experiments were conducted through five-flock growing cycles. Data analysis for trial 3 is ongoing and will be included in the future report by Wang et al. 2008)

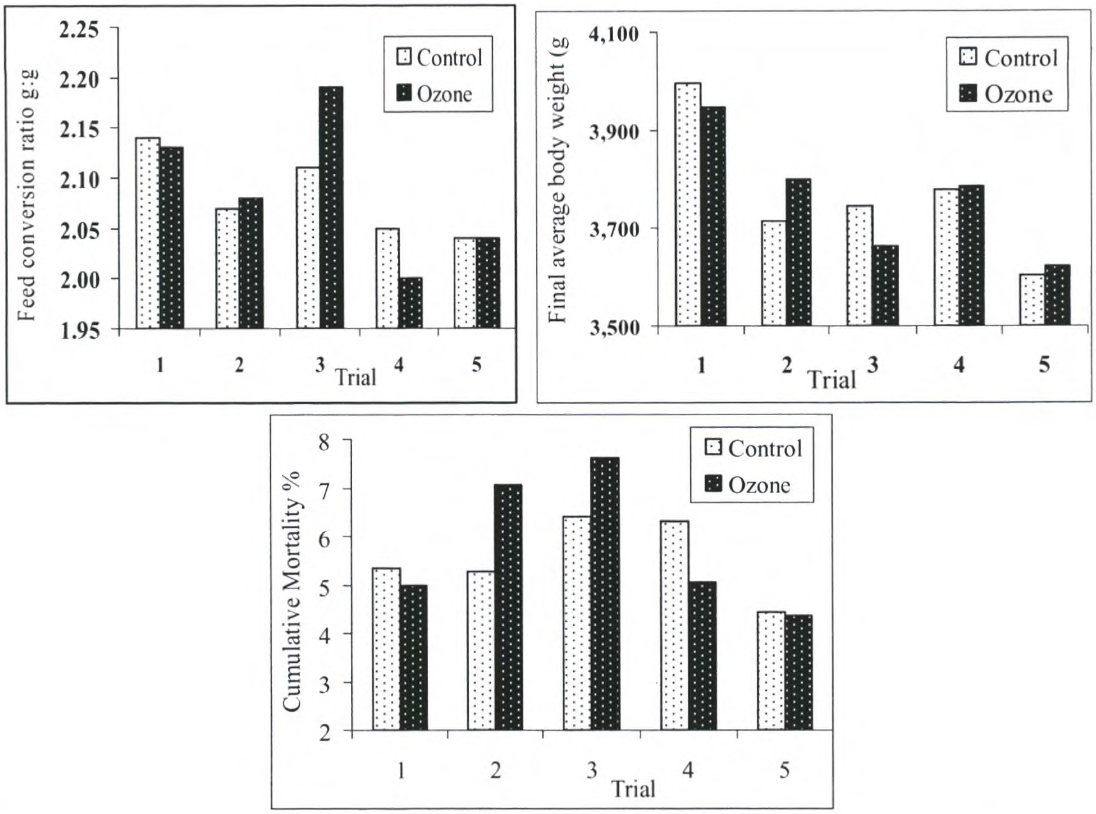

Figure 2. Broiler chicken performance comparison between control and treated (Ozone) houses through five flocks. (Each bar corresponds to the average of flocks of approximately 40,000 broilers. In feed conversion the lower the value the better the efficiency of broilers to transform feed in body weight. The age of flocks at processing vary between 58 and 63 days)

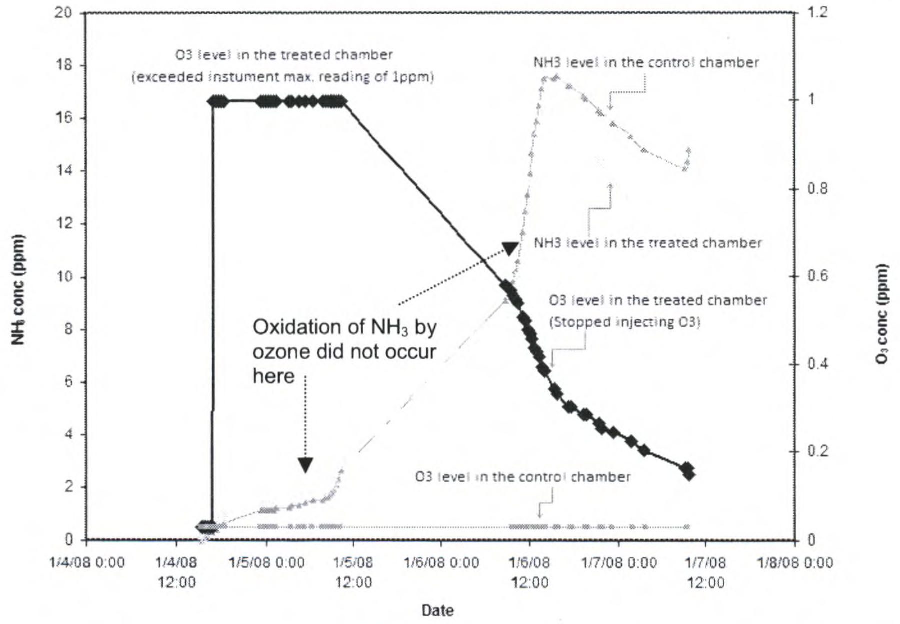

Figure 3 comparisons of ammonia and ozone concentrations in the treated and control chambers (laboratory study) (More details will be reported by Li et al., 2008)

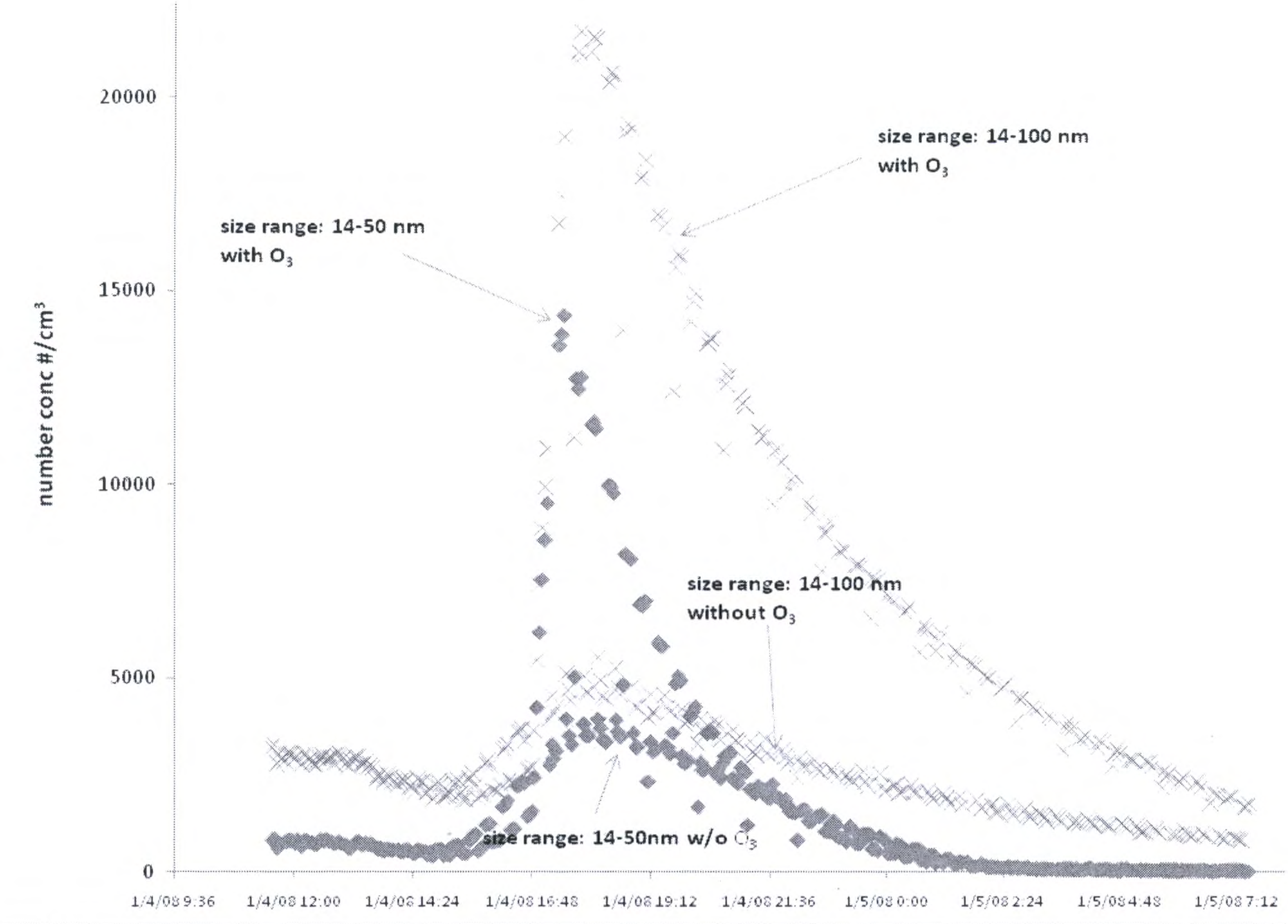

Figure 4. Comparison of aerosol number concentrations in the treated and control chambers (laboratory study)(More details will be reported by Li et al., 2008)

Cost:

The economic analysis for this reported project is very preliminary. Since no significant reduction in ammonia concentration was observed, the economic analysis was based only upon feed conversion ratios. The results of this analysis (table 1) indicate that after 5 flocks the ozonation treatment resulted in an economical loss of $345. Taking in consideration that installation costs are close to $20,000 for two houses, it is very unlikely that the use of ozonation is economically feasible to be used in the poultry industry.

Table 1. Analysis of economic impact of ozonation application

Flock	Age (days)	Average broiler live weight (lbs)		Total pounds of live weight produced[1]		Adjusted FC @ 7.5 lbs (g:g)[2]		Farm condemnations[3] (%)		Grower payment[4] ($)	
		Control	Ozone	Control	Ozone	Control	Ozone	Control	Ozone	Control	Ozone
1	62	8.81	8.81	340,720	337,533	1.90	1.91	0.27	0.24	17,160.51	17,173.08
2	62	8.19	8.19	319,520	320,848	1.94	1.92	0.17	0.21	16,905.52	16,489.53
3	64	8.26	8.26	302,860	299,440	1.97	2.08	0.25	0.24	15,708.78	14,337.94
4	58	8.33	8.33	327,900	331,071	1.90	1.84	0.41	0.45	16,164.42	17,632.58
5	59	7.95	7.95	331,100	333,100	1.96	1.95	0.38	0.34	19,955.93	19,917.54
Total	61	8.31	8.31	1,622,100	1,621,992	1.93	1.94	0.30	0.30	85,895.16	85,550.67

*Variance in grower payment in five (5) flocks: $344.49

[1] Every flock includes the chickens produced in two houses per treatment. In average each flock had 40,000 broilers at placement.

[2] Feed conversion standardized at 7.5 lbs body weight, taking in consideration feed consumption and average daily gain.

[3] Broilers with some type of defect at the market age that exclude them from processing.

[4] Net profit obtained per flock of two houses (40,000 broilers), before cost of labor, gas, electricity, taxes, and house and equipment depreciation. This includes cost of feed, day-old chickens, vaccines, bonuses due to improvements in performance compare to pair farms processing in the same week, and any additional water additives or therapeutic treatments when chickens suffered of disease.

Implementation:

In this reported study, ozonation technique was tested on a commercial broiler farm with four (42ft by 500 ft) identical tunnel ventilated houses with 21,500 broilers per house. This field evaluation consisted of five field trials utilizing the direct introduction of O_3 into the atmosphere of two commercial broiler houses paired with two control houses located on the same farm and placed at the same time over a period of five consecutive grow-out periods. Except for the ozonation, all flocks were managed in the same manner (feed, number of chicken, ventilation system setting). Flocks were grown out for periods of 58 to 63 days. Individual body weights were collected at 42 and 56 days of age from 200 birds sampled in groups of 40 from 5 representative areas from each house. Average flock weights for each house/flock were collected at the processing plant. Feed intake, mortality, and weight of mortality and morbidity were recorded for each house and feed conversion calculated based on the number of birds placed. Carcass condemnations, average carcass dressing percentage, were collected by house and flock from the grower's settlement sheets. In-house ammonia and CO_2 concentrations were continuously measured for a minimum of 48 hours per week for five grow-out periods using one portable multi-gas unit (PMU) (Gates, et al., 1995) per house. Ozone concentrations were monitored with GasAlert Extreme® (BW Technologies) data loggers as well as spot checked with colorimetric sampling tubes.

The laboratory study was designed to exam reaction of ozone and NH_3 under well-controlled condition. Seven experimental trials were carried out in the UNC 270 m^3 dual Teflon film outdoor aerosol smog chamber located at Pittsboro, NC. The chamber was divided into two separated rooms, of which one served as treated room and the other one served as control room. The same amount of layer manure (6 x 800 g) was placed in each room with emission area of 6 x (15cm x 10.5cm). Ozone was introduced into the treated room at various concentrations. Ozone concentrations in both rooms were monitored using a UV photometric ozone analyzer (TEI Model 49PS). Ammonia concentrations in both rooms were monitored using a chemiluminescence ammonia analyzer (TEI 17C). The particle size distribution (13 to 690 nm) was measured at 10 minute interval using a Scanning Mobility Particle Sizer (SMPS 3936 TSI, MN) composed of a Differential Mobility Analyzer (TSI long DMA, 3081, MN) and a Condensation Particle Counter (TSI CPC, 3022, MN).

Technology Summary:

House ozonation is a controversial technique that has been used in the literature for broiler house cleaning and in-house air contaminant control. Field evaluation in this reported study suggests that ozonation cannot effectively remove ammonia from air inside the broiler houses. Moreover, it caused a negative effect on feed conversion in two of the five flocks evaluated and in the average of five flocks. The laboratory study on this technique indicates that zone does not reaction with NH_3 in days even at ozone concentration above 1 ppm, which was more than 10 times higher than the health safety limit set by OSHA. The laboratory tests also show significantly higher level of fine/ultra fine particles / aerosols in the ozone treated environment as compared with the environment without ozone treatment. The direct application of ozonation technique for ammonia mitigation in the animal facilities is not recommended.

Additional Resources:

http://www.epa.gov/iedweb00/pubs/ozonegen.html

Acknowledgments:

This project was sponsored by the Animal and Poultry Waste Management Center (APWMC) at North Carolina State University and $AgriO_3$ Inc. The authors gratefully acknowledge the support from Professor Richard Kamens at University of North Carolina (UNS) at Chapel Hill and the use of his Aerosol Smog Chamber.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
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Atomization Treatment to Improve Air Quality in a Swine Concentrated Animal Feeding Operation (CAFO)

P. Juergens and G. Rapp
Juergens Environmental Control

Species: Swine
Use Area: Animal Housing
Technology Category: Chemical Amendment
Air Mitigated Pollutants: Particulate Matter, Viable Bacteria, and Ammonia.

Description:

Poor air quality within swine concentrated animal feeding operations (CAFOs) poses a threat to producers, social responsibility within local communities, and livestock production. Accordingly, a current study by Johns Hopkins Bloomberg School of Public Health was conducted to evaluate Juergens Environmental Control Systems for reducing air pollution including particulate matter (PM), viable bacteria, and ammonia within such a facility.

The technology consists of an acid-oil-alcohol aerosol applied daily. Its effectiveness was evaluated by comparing air quality from before to after treatment and between treated and untreated sides of a barn separated by an impervious partition. On the untreated side, air quality was typical for a swine CAFO, with mean PM2.5 of 0.28 mg/m3 and PMTOT of 1.5 mg/m3. The treatment yielded a reduction in PM concentration of 75-90% from before to after treatment. Effectiveness increased with time, application, and particle size (40% reduction for 1 *í*m and 90% for >10 *í*m). Airborne bacteria levels (total bacteria, Enterobacteriaceae, and gram-positive cocci) decreased one logarithmic unit after treatment. In contrast, treatment had no effect on ammonia concentrations. These findings demonstrate the effectiveness of an intervention in yielding exposure and emission reductions (Rule et al., 2005).

In addition to reducing PM concentration from the facility, other benefits to using the atomization solution have been reported as follows:

- Reduced allergy symptoms for farm workers due to reduced PM levels in the facility,
- Improved herd health through reduced mortality and morbidity rates,
- Better feed efficiency and faster pig growth rates,
- Consistent and uniform insect control throughout facility.

Mitigation Mechanism:

First process is the blending of the corn oil into a water formulation that includes alcohol, citric acid, eucalyptus, and vanilla to help mix the atomized aerosol, neutralize gaseous ammonia, and provide a pleasant odor, respectively. Second, the oil formulation is applied under high pressure, yielding micron-sized charged particles that efficiently remove PM through electrostatic attraction and coagulation.

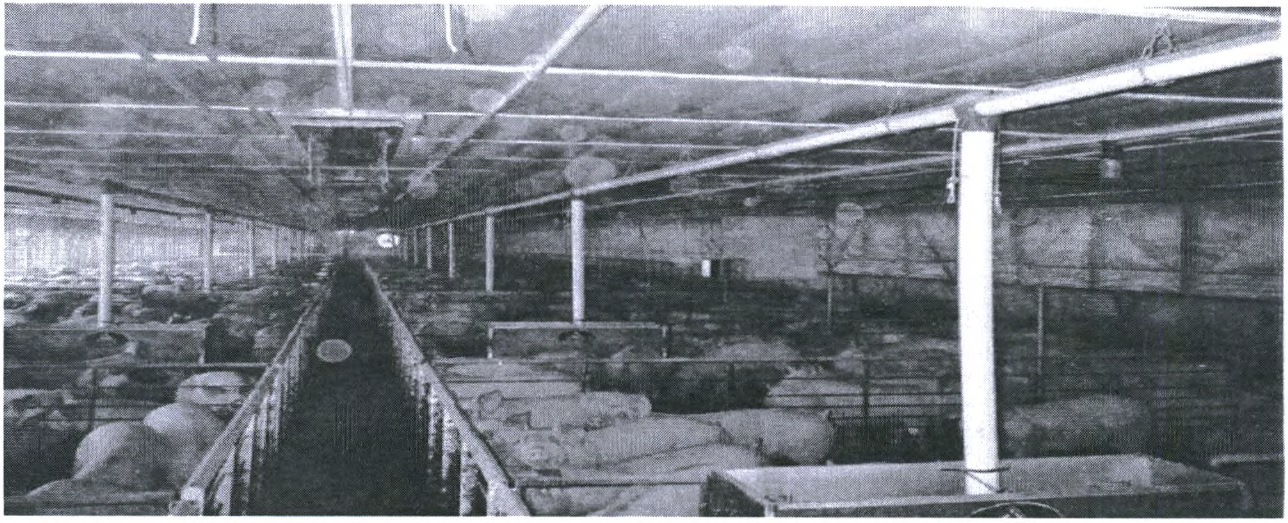
Alcohol is also used to keep nozzles sterilized and acts as an antibiotic that heal infectious cuts and abrasions that occur throughout a hog's life. Studies have indicated that citric acid makes antibiotics more readily available to the hogs. Eucalyptus is used for medicinal purposes, primarily focused on the respiratory systems. Eucalyptus helps make the air easier to breathe and helps clean the cilia in the producers and hogs nasal/lung passages. Vanilla is used as a deception to influence a positive smell not associated to the barn. Vanilla has also proven to be a pheromone for sows and in people helps to fight anxiety.

Applicability:

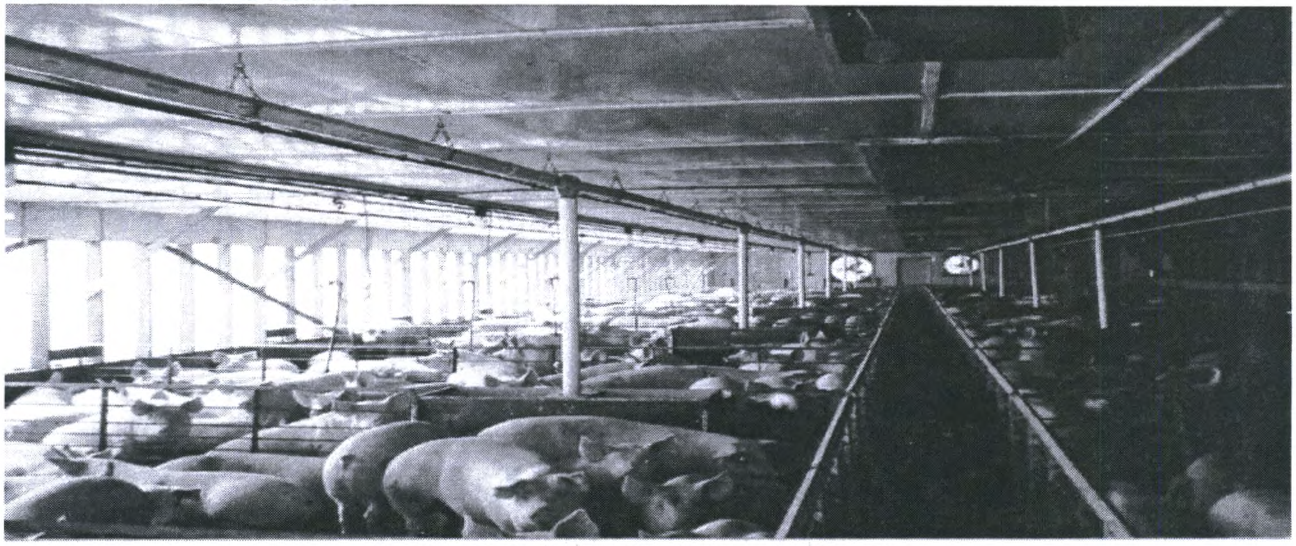
Atomization treatment is effective at mitigating PM, ammonia and odor emissions in swine housing systems, such as in swine finishing, breeding and gestation production systems. It has been determined through different field tests that applying the solution more frequently at a lower inclusion rate has suppressed the dust even more than initially recorded by Johns Hopkins Bloomberg. The more frequent applications also have shown dramatic reduction in ammonia generated by the aerobic environment.

Additional benefits recorded by producers in the field using the atomization solutions, are reduced allergy symptoms due to reduced PM levels in the facility. Improved herd health through reduced mortality and morbidity records. Better feed efficiency and faster pig growth rates plus consistent and uniform insect control throughout the facility.

Before Atomization / Dust Particulates



After Atomization / No Dust Particulates



Premium Air Quality For The Producer And Their Pigs!

Limitations:

Juergens Environmental Control suggests that the equipment is serviced twice a year. Service Technicians inspect the unit or units, checking for plugged nozzles and clean the filters inside the bio-security unit or units optimizing the best potential solution flow. Dust is encapsulated with oil through electrostatic attraction and coagulation and may stick to gating and fan louvers. The extra dust observed on fixed objects is suspended from re-suspension and will require to be cleaned more frequently to the manager's prerogative. Future high quality field studies are needed to record quantitative data of the application method and to achieve maximum reduction with minimum costs.

Cost:

Field application of the atomization system and solutions are subject to change. The fixed cost of the system for 1000 - 8000-pig finishing operation averages $1.96 - $7.79 per pig per 3 year term (shipping and installation labor not included). The cost of atomization operating averages $ 0.01 per pig per day over one year. The fixed cost of the system for 500-5000-sow operation averages $9.00 – $16.00 per sow per 3 year term (shipping and installation labor not included). The cost of atomization averages $.01 per sow per day over one year.

Implementation:

This solution is stored inside of an outdoor 8'X8'X8' utility shed called a bio-security unit. The bio-security unit is the brain of the system. It houses the computer that operates the system; The main pump for pressurizing the solution;

Valves that operate each manifold; Filters for each manifold; Electrical panel for all switches and fuses that operate the computer; And a 275 gallon tote to hold the solution. This unit is heated and centralized at each swine facility. The need for a bio-security unit is simply for operational purposes (i.e. Replenishing totes with solution and prevention of disease transmission).

The atomization manifolds are attached to the ceilings, which have nozzles spaced at either five or ten foot centers. In the breeding and gestation barns we require five foot centers due to the facility setup and uniform coverage that is recommended. In the finishing barns, they are required to be mounted on ten foot centers due to the facility setup and the uniform coverage that is necessary.

The computer is programmed to operate efficiently for different facilities. In the finishing facilities atomization occurs six times per day, once every four hours for only five seconds each cycle. In the breeding and gestation facilities the computers are programmed to atomize three times a day, once every eight hours for only three seconds each cycle. This is done simply to only cover the adequate amount of square footage recommended per animal space. Daily usage is subject to barn size.

In the beginning cycle the computer tells the system to start the atomization sequence. The system starts and agitates the solution in the tote for ten minutes to get the atomization solution into full suspension. Once the solution is in total suspension the pump pressurizes the solution throughout the manifold at 235 psi (1620 kPa) and a rate of 45 mL/m2 and pushes the solution through the special manufactured nozzles to produce an aerosol mist for three to five seconds depending on the facility. The mist fills the barn collecting dust particulates magnetically and creating an acid base reaction that neutralizes the odors and gases present in the aerobic environment; providing a healthy atmosphere.

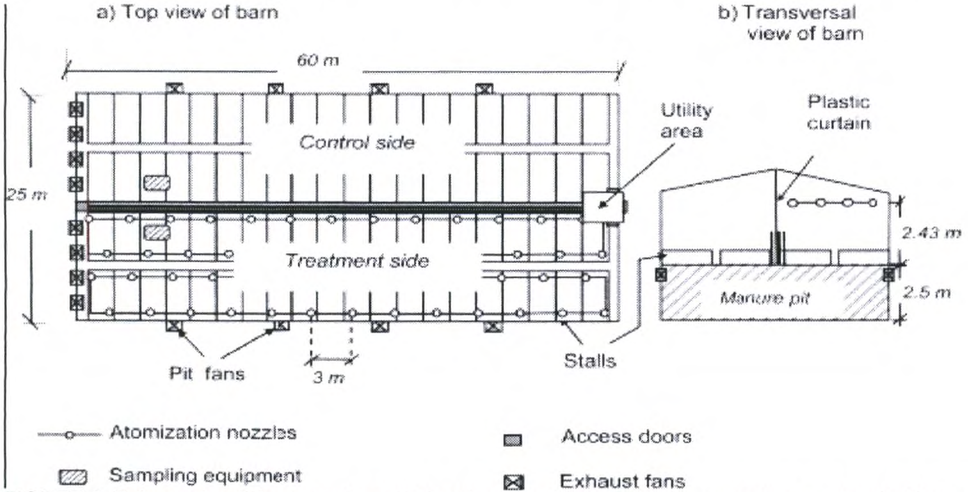
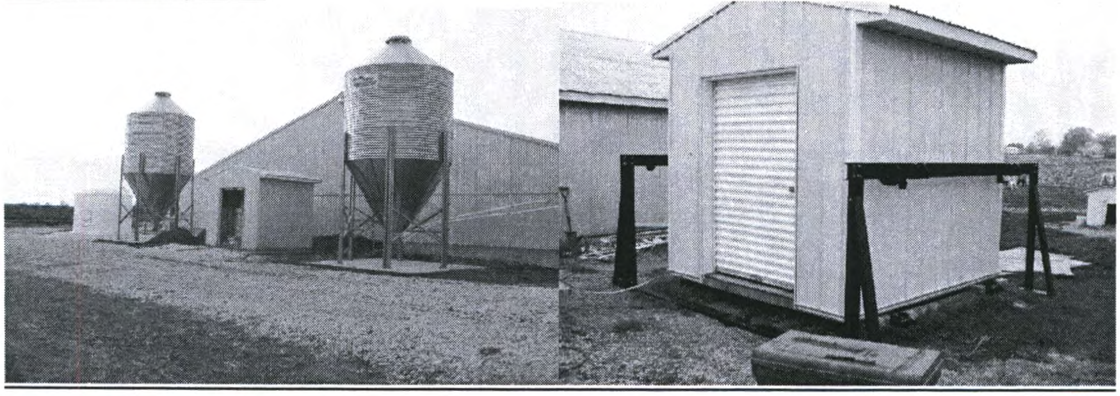
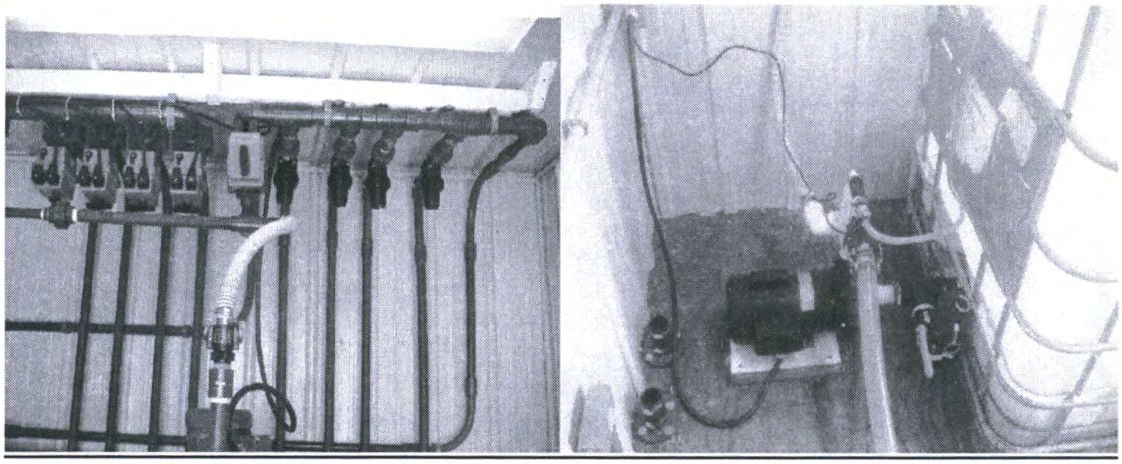


FIGURE 1. Schematic of the tunnel ventilated barn and location of access doors, atomization nozzles, sampling stations, and fans: (a) top view, (b) transversal cut. (Not to scale.)

Bio – Security Unit





Technology Summary:

Juergens Environmental Control Systems and the application of atomization solution demonstrate the effectiveness of oil atomization in reducing airborne PM levels within CAFO s. It logically follows that reductions indoors will yield proportional reductions in PM levels emitted into the surrounding community. The availability of Juergens Environmental Control Systems holds promise for reducing producer and community exposures to PM. Furthermore, because CAFO s can potentially fall within the definition of a stationary source under the Clean Air Act, the U.S. EPA and state governments have the authority to require that CAFO s measure and control their emissions. Juergens Environmental Control Systems and the application of atomization solution could help bring a CAFO in compliance for PM standards.

Acknowledgments:

Ana M. Rule, Amy R. Chapin, Sheila A. McCarthy, Kristen E. Gibson, Kellogg J. Schwab, and Timothy J. Buckley.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
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Iowa Farm Bureau Federation
Iowa Egg Council
Iowa Pork Industry Center
Iowa Pork Producers Association
U.S. Pork Center of Excellence

Odorgon: Overhead Spray System to Neutralize Odors

S. Opheim
Vice-President Klean Air Inc.

Species:	Swine, Poultry, Beef & Dairy
Use Area:	Animal Housing
Technology Category:	Chemical Amendment
Air Mitigated Pollutants:	Ammonia, Hydrogen Sulfide, Odor

Description:

Odorgon is a water based formulation that is applied in CAFO's through a high pressure mist system. Odorgon is sprayed on an automated timer basis from the ceilings of facilities to **neutralize** malodors. Results include overall better animal performance, improved conditions for employees and workers, and better neighbor relations.

Mitigation Mechanism:

Odorgon is referred to as an "odor neutralizer" , not a masking agent or perfume. Odorgon is a proprietary formulation whose major ingredient belongs to unique class of cationic surfactants. In addition to enhancing the solubility of specific amines such as ammonia, and sulfur containing compounds like hydrogen sulfide in the aqueous spray, Odorgon acts as a buffer reacting with these gases and resulting in the formation of weak non-volatile organic salts. Other organic compounds formed during the buffering process are subject to oxidation or reduction reactions while in solution.

Water is the universal scrubber of malodors. The efficiency of gaseous removal from the immediate atmosphere is related to the size and speed of the droplets creating a surface area exposure as well as temperature and length of time the gases are held in solution. The method of application is a sprayed or atomized solution at 600 psi,contaning 50 parts water to 1 part Odorgon concentrate. The compound dispersal is generally for 10 seconds on, every 20 minutes but usage may vary on a seasonal basis.

Applicability:

Odorgon is currently used primarily in Swine confined animal feeding operations but also may be used for poultry, beef and dairy. Current facilities include

- Finishing
- Nursery
- Breeding/Gestation
- Farrowing

Facilities installed are in Iowa, Minnesota, South Dakota, Nebraska, Illinois, Missouri, North Carolina and Canada.

Limitations:

Since Odorgon is a water based product, installation and application must be in environments not subject to freezing conditions. Some producers choose not to run the system on days when the building curtains are down with high wind conditions. Other producers choose to run the system year round.

Cost:

Capital equipment cost for a typical 42 x 200 foot finishing barn with installation labor is $4900. Annual operation cost is .73 (cents) per animal produced for a finish barn and .19 (cents) per head for a nursery barn. Equipment costs will fluctuate based on building layout, square footage, number of pens and desired results.

Implementation:

The Odorgon system should be located in the area of the barn near the controls and adjacent to water and electrical sources. The system consists of the following components:

- Direct drive electrical motor
- High pressure pump
- Hydrominder (injects water 50 parts to product 1 part
- Mix tank

- Timer
- High pressure nylon line
- Stainless steel compression fittings
- Brass nozzles with stainless steel tips
- Concentrate tank (15 gallons)
- Angle iron mounting bracket

Two lines are installed the length of the barn from the ceilings with a nozzle spaced every 10 feet usually over the center of pens. A 42 x 200 barn with would require 40 nozzles.

Technology Summary:

The Odorgon system utilizes a high pressure mist system to neutralize malodors inside the buildings primarily for the benefit of the animal. Other benefits include improved working conditions and improved neighbor relations. Components of the equipment are of high caliber with low maintenance for lasting durability in a harsh environment.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
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Iowa Pork Producers Association
U.S. Pork Center of Excellence

Animal Housing-Amendments

Effectiveness of Litter Treatments for Reduction of Ammonia Volatilization in Broiler Production

J.P. Blake, J.B. Hess, and K.S. Macklin
Department of Poultry Science, Auburn University

Species:	Poultry (Broiler)
Use Area:	Animal Housing
Technology Category:	Chemical Amendment
Air Mitigated Pollutants:	Ammonia

Description:

In commercial broiler production, a little over one ton of litter is produced per 1,000 birds and during the course of a year this could lead to 125 tons produced per 20,000 bird house. Built-up litter propagates higher in-house ammonia levels, which can adversely affect poultry health by making the birds more susceptible to respiratory diseases. Techniques to reduce ammonia levels and pathogenic microbes include changes in management practices and use of litter treatments. Most litter treatments are typically effective for only 3-4 weeks; whereas, broilers are housed for six or more weeks prior to slaughter. Information to be presented summarizes a series of experiments that evaluated six litter treatment strategies applied at three levels in reducing ammonia volatilization during broiler production: Poultry Litter Treatment (PLT^{TM}), granulated aluminum sulfate (Al-Clear^{TM}), Poultry Guard^{TM}, hydrated lime, liquid acidified aluminum sulfate (A-7^{TM}), and concentrated sulfuric acid.

Mitigation Mechanism:

Interest in the use of litter treatments has steadily increased over the last decade as growers and technical personnel alike recognize the health and productivity benefits of improving the broiler house environment. It is known that high ammonia levels make birds more susceptible to respiratory diseases. Numerous laboratory and field studies have shown how ammonia levels as low as 10 ppm affect bird health and performance (Carlile, 1984). Ammonia levels above 25 ppm in the poultry house can damage the bird's respiratory system and allow infectious agents to become established, leading to declining flock health and performance. Resistance to respiratory disease may be decreased and *E. coli* bacteria can be significantly increased in the lungs, air sacs and livers of birds exposed to ammonia because of damage that occurs to the tracheal cilia. In addition, body weight, feed efficiency and condemnation rate may be compromised in birds exposed to levels of ammonia exceeding 10 ppm.

Most litter treatments used in the broiler industry involve chemical reduction of litter pH so that bacteria associated with ammonia release are either inactivated, reduced in number or both. The volatilization of ammonia has been attributed to microbial decomposition of nitrogenous compounds, principally uric acid, in poultry house litter. Once formed, free ammonia will be in one of two forms: as the uncharged form of NH_3 (ammonia) or the ammonium ion (NH_4), depending on litter pH. Ammonia volatilization remains low when litter pH is below 7.0, but can be substantial when above 8.0. Uric acid decomposition is most favored under alkaline (pH>7) conditions. Uricase, the enzyme that catalyzes uric acid breakdown, has maximum activity at a pH of 9. As a result, uric acid breakdown decreases linearly for more acid than alkaline pH values. One principal ureolytic bacterium, *Bacillus pasteurii*, cannot grow at neutral pH, but thrives in litter above pH 8.5. Typically, litter pH in a broiler house ranges between 9-10.

Gaseous emission of NH_3 can be inhibited if converted to NH_4^+ (ammonium); which can be accomplished by lowering litter pH. In general, an effective litter treatment results in the production of hydrogen ions (H^+) when it dissolves and the hydrogen ions produced by this reaction will attach to ammonia to form ammonium, which further reacts with sulfate ions to form ammonium sulfate $(NH_4)_2SO_4$**.** Ammonium sulfate is a water-soluble fertilizer. As a result of these acid-based reactions, the amount of ammonia emitted from the litter will be reduced; which should increase the nitrogen (N) content of the litter.

Applicability:

The main goal in using a litter treatment is to effectively reduce ammonia emissions from poultry facilities, which will have a direct effect on improving litter management, nutrient enrichment, and reducing ammonia volatilization from poultry house litter. Recent research completed in the Department of Poultry Science at Auburn University has focused on a series of litter treatment experiments to evaluate six litter treatments at three application levels to evaluate their ability to prolong litter usage and to reduce ammonia volatilization and pathogenic microorganisms associated with this material. Poultry Litter Treatment (PLT^{TM}), granulated aluminum sulfate (Al-Clear^{TM}) (GA), Poultry Guard^{TM} (PG), and Hydrated Lime (HL), were applied at 24.4, 48.8, or 73.2 kg/100 m^2 (50, 100, or 150 lbs/1000 ft^2); a liquid acidified aluminum sulfate (A-7™) (LA), was applied at 81.4, 162.8, and 227.1 L/100m^2 (20, 40 or 60 gal/1000 ft^2); and concentrated sulfuric acid (98% H_2SO_4) (SA) was applied at 9.75, 19.50, and 29.26 kg/100m^2 (20, 40, or 60 lb/1000 ft^2) on new pine sawdust bedding and tested against a non-treated control (CON).

In each experiment, a total of 1120 commercial broiler chicks (Cobb X Ross) were obtained from a commercial hatchery and were randomized with 70 birds assigned to each of 16 enclosed chambers (2.44 x 2.44 x 2.44 m; 8 x 8 x 8 ft). Birds were fed a corn-soybean meal starter (0.68 kg/bird; 22% CP, 3087 kcal/kg ME), grower (1.36 kg/bird; 20% CP, 3131 kcal/kg ME), finisher (1.81 kg/bird; 17.5% CP, 3197 kcal/kg ME) and withdrawal (c.a. 1.36 kg/bird; 16.5% CP, 3219 kcal/kg ME) to meet or exceed NRC (1994) requirements. New pine shavings (54.42 kg; 120 lbs) were placed in each pen at the start of each experiment. Feed and water were provided *ad libitum* with 24 hr light. Birds and feed were weighed at 21, 42 and 49 d to determine growth and feed performance. Litter and air quality samples were obtained for analysis initially and weekly through day 49. Ammonia measurements were conducted using a closed container of specified dimension (46 x 36 x 12 cm; 21 x 15.5 x 5 in) inverted over the litter bed and determined using a Drager CMS Analyzer equipped with a remote air sampling pump and appropriate ammonia sampling chip (0.2-5, 2-50, or 10-150 ppm). The tube from the sampling pump was located in the top center of the container. The sampling pump was evacuated (calibrated) for 60 seconds followed by a measurement period of up to 300 seconds. Most readings were usually achieved with 60 seconds following evacuation. Litter was collected weekly, starting the day prior to chick placement and continued through day 49. Collection was performed in each pen by using the grab sampling technique. Individual litter samples (3g) were mixed with 60 ml distilled water for pH measurement. Data from these experiments was analyzed by analysis of variance using the General Linear Models procedure of the Statistical Analysis System (SAS Institute, 1997). When significant ($P<0.05$), means were separated by Tukey's HD multiple comparison procedure.

There were no differences ($P>0.05$) in growth performance in any experiment attributed to type or level of litter treatment. Initial litter pH was significantly lower ($P<0.05$) for PLT, GA, PG, LA, and SA treated pens as compared to CON (ca 2.3 vs. 6.4) and was influenced by level of application. Results indicated that PLT, GA, and LA significantly ($P<0.05$) reduced ammonia volatilization as compared to CON through day 42 at the intermediate and highest application rates. SA significantly ($P<0.05$) reduced ammonia volatilization through day 35 at only the highest application rate as compared to CON. Although PG exhibited the ability to lower pH, it failed to elicit a significant ($P>0.05$) reduction in ammonia. Conversely, HL elevated litter pH initially as compared to CON (12.8 vs. 6.3), but this effect disappeared after day 21. HL failed to support any reduction in ammonia volatilization. Litter analysis results did not indicate a significant ($P>0.05$) increase in amount of nutrients retained due to treatment. Results indicate that PLT, GA, LA, and SA were capable of reducing ammonia volatilization during broiler production. Results show that higher levels of litter treatments can extend ammonia control and may contribute to improvements in bird health. In these trials, ammonia levels were often controlled at the intermediate and highest application levels for up to 42 days (starting with new pine shavings litter).

Limitations:

Litter treatments, by nature, can be corrosive and hazardous to work with and appropriate measures as defined by the manufacturer should be observed during handling and application procedures. As with any acid-based material, gloves, eye protection and appropriate clothing should be used. In some cases the litter treatment may be applied by a professional applicator, thus reducing hazards to the producer during handling and application.

Cost:

The delivered cost of a litter treatment is highly dependent upon transportation costs and competitive pricing offered among manufacturers and distributors. Also, costs for transporting, handling, and applying dry versus liquid products should also be considered. Due to the competitive nature of pricing for the various litter treatment products it is difficult to provide a reasonable and consolidated cost for the treatments tested in these experiments. However, it can be concluded that low levels (50 lb/1000 ft^2) only provide ammonia control during the brooding period (maybe for 3 weeks); whereas higher application rates will extend the effective period for ammonia control, but the producer must balance the cost of applying a higher level of litter treatment with benefits associated with longer ammonia control.

Implementation:

Originally, litter treatments were placed at a relatively low level (generally 50 lb/1000 ft^2) to give early ammonia control during the brooding period. More recently, higher levels have been suggested as the industry becomes more comfortable with the performance benefits associated with improving air quality in the broiler house with litter treatment use. Broiler growers must balance the cost of applying extra amounts of a litter treatment and benefits associated with longer ammonia control. In general, though, improved bird health normally translates into improved broiler weights and improved feed efficiency.

A principal question for those involved in poultry production is: "What is the best litter treatment?" Unfortunately, this most frequently asked question has no general answer and the difficulties in addressing this question may be complicated and numerous. There has never been an experimental study evaluating the various litter treatment products under various management conditions. Litter moisture, brooding and lighting programs, ambient temperature, strain type, ventilation management, litter management, and disease challenge are only a few of the variables that have a potential impact on product selection, efficacy and potential return on investment.

In selecting a litter treatment product, one must identify the goals for application. Litter treatments may be cost-effective and justifiable under one or more of the following situations:

- high fuel prices
- extreme cold weather
- short layout periods
- persistent disease challenges
- severe vaccination reactions
- reduction of ammonia-related stress
- prolonged litter reuse
- increased bird density
- address marginal management or housing situations

In general, control of house ammonia level is the primary purpose for using a litter treatment. In recent years, reasons for using a litter treatment and any potential benefits from its use have expanded to include improvements in performance and environmental concerns. Some litter treatments may be used to enhance the composition of the litter as a fertilizer or as part of a best management practice to reduce food-borne pathogens. Ammonia-reducing litter treatments offer a potentially better in-house environment for the birds. They may also play a role in reducing ammonia and odor emissions from poultry facilities. Although different litter treatments vary in their ability to control ammonia, each offers a unique set of characteristics that need to be considered in selecting the appropriate product to meet an individual's needs. The litter treatment that offers the best return on investment will depend on the user's ability to select the product that best meets application goals.

To maximize the effectiveness of any litter treatment, one must properly prepare and apply the litter treatment in addition to managing the house and litter. Prior to application of any litter treatment, the house needs to be de-caked or tilled. Afterwards, the litter treatment can be broadcast at the chosen level using a drop or cyclone spreader or spray applied. Before birds are placed in the house, spills or concentrated areas should be raked into the litter to prevent consumption by the young birds. As with any litter treatment product, the rate selection for an individual's operation will be dependent on current management practices and needs based on such factors as ventilation control and litter moisture levels. Higher rates may be recommended when high ammonia conditions prevail. Litter treatments have become a common means of improving the broiler house environment throughout much of the broiler industry. It is likely that the use of these products will continue as growers manage reused litter to their best advantage.

Technology Summary:

Recently, poultry producers have come under increased regulatory scrutiny regarding the amount and type of emissions exhausted from poultry housing during the course of normal house ventilation. Ammonia and dust have both been discussed as potential problems with poultry house exhausts. The main goal in using a litter treatment is to effectively reduce ammonia emissions from poultry facilities, which will have a direct effect on improving litter management, nutrient enrichment, and reducing ammonia volatilization from poultry house litter. Research completed by the Department of Poultry Science at Auburn University indicates that increased levels of litter treatments can extend their ammonia control usefulness and most worked well with the exception of lime. In these experiments, ammonia levels were often controlled at the intermediate and highest level of application for 35 to 42 days. If more strict environmental regulations are put into effect regarding ammonia emissions from poultry facilities, litter treatments may become an important technique to allow producers to remain compliant.

The delivered cost of a litter treatment is highly dependent upon transportation costs and market competitiveness amo manufacturers and distributors. Also, costs for transporting, handling, and applying dry versus liquid products should also considered. Due to the competitive nature of pricing for the various litter treatment products it is difficult to provide reasonable and consolidated cost for the treatments tested in these experiments. However, it can be concluded that l levels only provide ammonia control during the brooding period (maybe for 3 weeks); whereas higher application rates extend the effective period for ammonia control, but the producer must balance the cost of applying a higher level of lit treatment with benefits associated with longer ammonia control.

Additional Resources:

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
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Bioaugmentation of Treatment System for Skatole Degradation: Bioremediation Potential for Odors Reduction at Livestock Operations

N. Lovanh, J. Loughrin, and K. Sistani
USDA-ARS, AWMRU, Bowling Green, KY 42104

Species:	Swine and poultry
Use Area:	Manure Treatment
Technology Category:	Biological Amendment
Air Mitigated Pollutants:	Odors

Description:

Animal waste disposal and odor control have become a major issue for animal production facilities. As an attempt to improve efficiency and profit margins, many livestock operations have become large concentrated rearing facilities. As a result, many concerns over potentially adverse environmental impacts from these operations have arisen. While there are many important issues that drive these concerns, the emission of malodorous compounds is undoubtedly the foremost factor driving public awareness of this matter. Odor management has become a crucial issue for the livestock industry. Many have attempted to mitigate malodorous emissions by utilizing technological techniques such as scrubbers. However, these techniques may not be cost effective since scrubbers may require expensive solvents. Here, we demonstrate that bioaugmentation of bioreactor with enrichment cultures and with a pure culture of *Rhodococcus* sp. isolated from swine lagoon is a viable alternative in reducing skatole, a main malodorous compound in swine effluent. We found that bioreactor amended with pure culture can degrade skatole as well as the enriched mixed culture after certain lag period. Pure culture bioreactor required longer lag time than the mixed culture. Thus, bioaugmentation of treatment systems with indigenous populations may increase the efficiency of treatment systems and provide a simple, cost-effective bioremediation potential in reducing malodors emission at livestock facilities.

Mitigation Mechanism:

Malodorous compounds are produced from fresh feces and from waste receptacle. Although the volatile compounds emitted from concentrated animal feeding operations are diverse, a limited number of these may be responsible for malodor (Williams, 1984; Hobbs et al., 1995; Zahn et al., 2001). Some of the most offensive compounds such as skatole, indole, cresol, and other phenolic compounds are products of the anaerobic metabolism of aromatic amino acids (Elsden et al., 1976). They are often cited as being the major malodors from livestock operations. Besides having characteristics of fecal odors, these compounds also have low thresholds for olfactory detection. By having treatment systems (e.g., bioreactors, biofilters, or bioscrubbers) that utilize microorganisms with specific enzymes for degrading these malodorous compounds, the resulting air quality around livestock operations would become less offensive. By bioaugmenting the treatment systems with specific degraders, a specific malodorous compound could be targeted which would improve the efficiency of the treatment systems.

Applicability:

Bioaugmentation is suitable for any treatment systems such as bioreactors, biofilters, and scrubbers. In turn, these systems could be utilized at livestock operations such as swine and poultry houses.

Limitations:

Dealing with living organisms requires the right environmental conditions for growth and sustainability. For example, the right pH (usually neutral), ambient temperature, sufficient amount of essential nutrients and oxygen are required for these aerobic skatole degraders. They are substrate-specific organisms. In addition, potential competition from indigenous species may limit their effectiveness.

Cost:

The cost of bioaugmentation of a treatment system is dependent upon the type of the treatment systems. These microorganisms can be easily isolated and cultivated from contaminated sites. The extent of the cost would fall mostly on the purchase of nutrients for growth. In most cases, the required nutrients for growth could be obtained from the target pollutants themselves (e.g., emissions from swine or poultry wastes).

Implementation:

The data given in this section show the degradation of skatole and p-cresol as a co-substrate in a bioreactor setting. These microorganisms can be used in biofilter and scrubber settings as well.

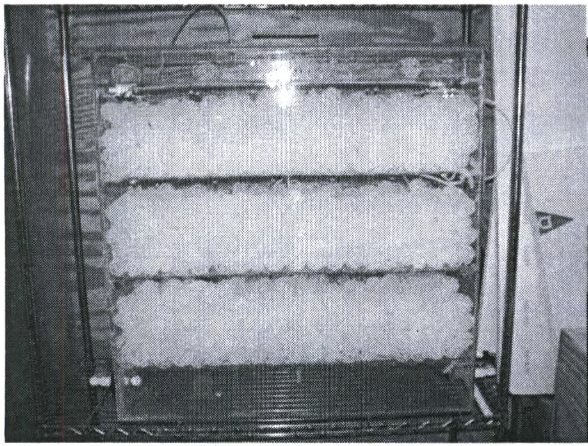

Figure 1. Bioscrubber setup (lab scale)

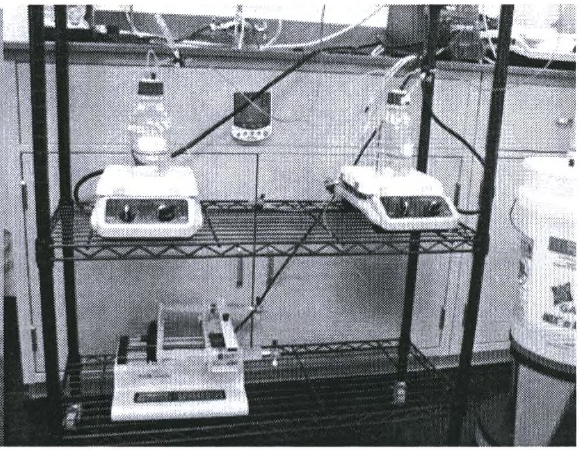

Figure 2. Bioreactor setup (lab scale)

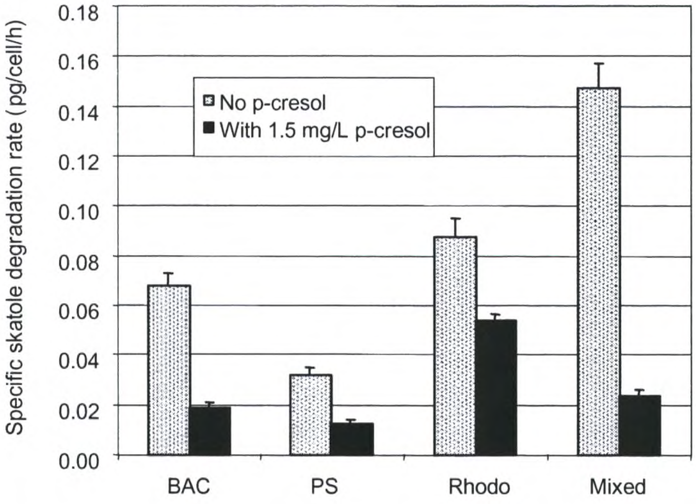

Figure 3: Effect of p-cresol on skatole metabolic flux for different archetypes fed 1 mg/L skatole at D=0.25h^{-1}. (BAC=*Bacillus sp.*, PS=*Pseudomonas stutzeri*, Rhodo=*Rhodococcus sp.*, and Mixed=*Mixed culture*)

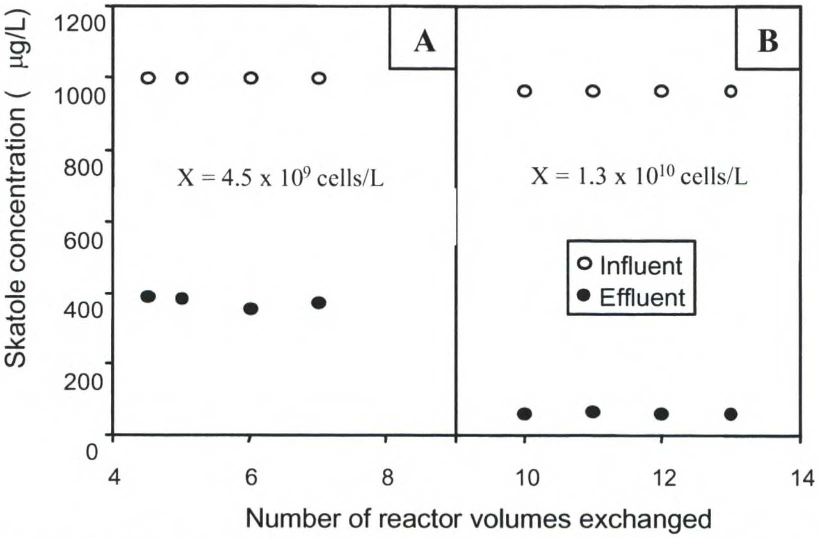

Figure 4: Skatole degradation by *Rhodococcus sp.* at 20 °C. The addition of p-cresol at 1.5 mg/L (Panel B) enhanced the degradation of skatole due to an increase in the microbial concentration (X).

Technology Summary:

Bioaugmentation of treatment systems (i.e., bioreactors, biofilters, or scrubbers) could increase/improve treatment efficiency and provide a simple, cost-effective bioremediation potential in reducing malodors emission at livestock facilities. Use of microorganisms such as these skatole degraders could effectively target the pollutant of interest. However, this could limit the technology in its applicability for general application since it is very substrate/pollutant specific. Nevertheless, this technology is simple to utilize, cost-effective, and applicable in most treatment systems.

Additional Resources:

Literatures on environmental microbiology.

Acknowledgments:

We would like to thank Michele Reliford and Michael Bryant for their technical assistance.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
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Iowa Pork Producers Association
U.S. Pork Center of Excellence

The Effects of Acidifier Application In Reducing Emissions from Dairy Corrals

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Species:	Dairy
Use Area:	Animal Housing
Technology Category:	Chemical amendment
Air Mitigated Pollutants:	Methanol, Ethanol

Description:

Methanol and ethanol are produced during anaerobic fermentation in the cow's rumen by microbial strains like *Streptococcus bovis* and *Ruminococcus albus.* Fresh slurry contains both of these alcohols and many volatile organic compounds (VOC) forming bacteria. Environmental drivers such as pH, temperature, and oxygenation of the slurry affect both microbial and physical processes that determine which alcohols are produced, metabolized by bacteria, and transferred from liquid to gas phase. Therefore, mitigation must address at least one of the main environmental drivers (e.g., pH) to effectively disrupt microbial and enzymatic activity and reduce gas release into the atmosphere (Jongebreur and Monteny, 2001).

Sodium bisulfate (NaHSO4, SBS) is a dry, granular acid salt that has been extensively used for many years as a pH reducer in a variety of agricultural applications (Sweeney et al., 1996; Sweeney et al., 2000). It is also used in the dairy industry to reduce ammonia emissions and bacterial counts in bedding, prevent environmental mastitis, and calf respiratory stress.

Streptococcus bovis bacteria does not grow in the presence of elevated sodium concentrations (5-6%) and there is a cessation of *Rumenococcus albus* growth at a pH of 6.0 or below, so the application of acidifying SBS could conceivably reduce the growth and survival of these alcohol-producing organisms (Schlegel et al., 2003; Thurston et al., 1993). Alcohol, amine, and ammonia losses from freshly excreted manures to the atmosphere occur very rapidly and effective mitigation needs to be implemented shortly after excretion (Meisinger et al., 2001). Acidification of manure slurry has also been suggested in the literature (Meisinger et al., 2001; Clemens et al., 2002).

ParlorPal (SBS, Jones-Hamilton Co.) is used for controlling ammonia and VOC emissions in animal stalls and animal production facilities and can be applied to dairy drylot corrals with tractor driven fertilizer spreaders or by hand application
In addition to reducing VOC emissions from the facility, it can be used to reduce flies population on dairies.

Mitigation Mechanism:

Sodium Bisulfate is a hygroscopic mineral acid salt and as ambient moisture is adsorbed into the SBS bead. The component dissociates into its sodium (Na^+), hydrogen (H^+), and sulfate ($SO4^-$) ions upon application to the manure, bedding or drylot surface. The hydrogen ion reduces the pH to a level that is not consistent with propagation of bacteria associated with VOCs production.

The reduction in pH reduces bacterial populations by 3-5 logs including reductions in coliforms, salmonella, clostridium, and campylobacter Sodium bisulfate is approved by the FDA for animal and human food use and by the EPA as a surface amendment for ammonia reduction and general bacterial reduction.

Applicability:

Emission studies conducted in our lab have identified alcohols (methanol and ethanol) as the major VOC group originating from fresh waste and fermented feedstuffs (Shaw et al., 2007; Sun et al., 2008).. Effective control of alcohol emissions could help meeting regulatory standards, satisfy public concerns, and improve local and regional air quality.

The present study was conducted at the University of California, Davis. In earlier study, SBS has been shown to be effective in the mitigation of ammonia and alcohols emissions from fresh dairy slurry (Sun et al., 2008). Therefore, SBS effectiveness was investigated under drylot corral conditions in a large scale study. A total 128 dry Holstein non-lactating cows were sorted into groups of eight cows and were housed in totally enclosed dirt-floored corral pen enclosures. This study focused on application rates under production-like conditions.

SBS application was effective at mitigating methanol (MeOH) and ethanol (EtOH) from dairy drylot corrals (Figures 1 and 2). The mitigation also offers a potential solution to MeOH and EtOH emission reduction in dairy exercise pens.

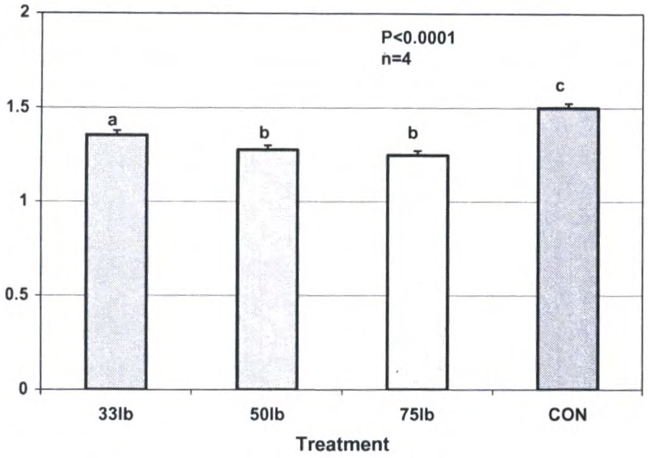

Figure 1. Effect of treatment on methanol emissions

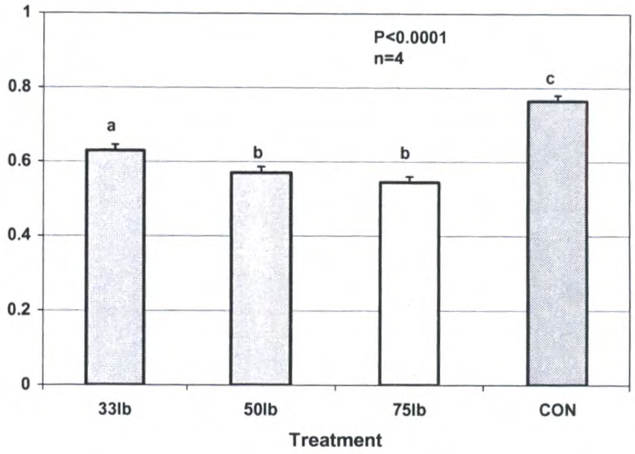

Figure 2. Effect of treatment on ethanol emissions

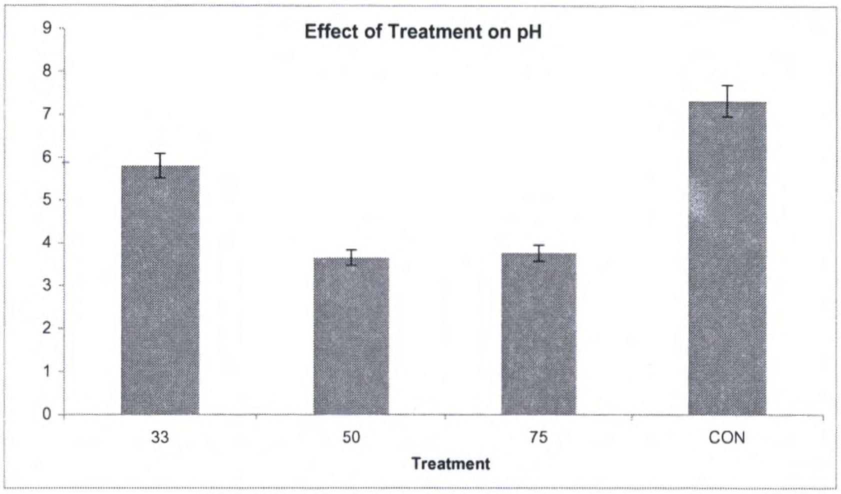

Figure 3. Effect of treatment on pH

We found that SBS is most effective at an application rate of 50 lbs over 1000 ft^2 at three times a week application or 75 lbs applied over 1000 ft^2 twice a week. At the application rate, SBS was only used around feed bunks and water troughs and at apparent manure accumulation spots. This application rate reduced emissions of methanol and ethanol most effectively (see figures 1 and 2) with out causing formation of other emissions. Sodium bisulfate can be applied while animals are present in the pen. This research has demonstrated reductions of methanol and ethanol of 27% and 17%, respectively.

SBS also offers a potential in reducing certain pathogens and fly larvae due to the acidic environment induced by the application. This reduction in pH (see figure 3) caused by SBS application could reduce pathogen loads in animal housing areas as well as reduce fly populations on the dairy. This could potentially reduce disease prevalence in the herd and improve animal welfare.

Limitations:

Sodium bisulfate is a mineral acid salt. Appropriate measures, as defined by the chemical supplier, should be used during the handling of SBS.

In locations that are sensitive to salt or areas with existing high salt loading in soils, applications of SBS should be considered with care because sodium is one of its components. Application at high rates could cause formation of nitrous oxide.

In addition, SBS must be applied consistently to manure to maintain constant emission reduction as the substance looses its effectiveness over time.

Cost:

Bulk cost of product delivered to the farm is $660.00/ ton. Application at 50 to 75 lb / 1000 ft^2 2X / week equates to costs of between $33.00 to $49.50 / 1000 ft^2 / week. Treatment of heavy use areas, approximately 30% of the total pen area, reduces total pen cost by 70%. Cost / cow assuming 4 cows / 1000 ft^2 of pen area would be $2.48 to $3.71 / week treating only the heavy use areas.

Implementation:

There are no special requirements to implement this program. A fertilizer type spreader is required.

Technology Summary:

Sodium bisulfate application is an acidifier method that can effectively mitigate alcohol (methanol and ethanol) emissions from dairy slurry.

Additional Resources:

http://www.jones-hamilton.com/products.html

Acknowledgments:

Project support was provided by the California State Water Resources Control Board and the Merced County Department of Environmental Health as well as by Jones-Hamilton Co.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
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Use of Sodium Bisulfate to Reduce Ammonia Emissions from Poultry and Livestock Housing

T. Marsh Johnson[1] and Bernard Murphy[2]
Veterinary & Environmental Technical Solutions, PC[1]; Jones-Hamilton Co.[2]

Species: Poultry (broiler, layer & turkey), cattle, and horses
Use Area: Animal Housing
Technology Category: Chemical Amendment
Air Mitigated Pollutants: Ammonia & Volatile Organic Carbons

Description:

Ammonia (NH_3), volatile organic compounds (VOCs) and greenhouse gases (GHG) of animal manure origin are produced by microbial activity on the nitrogen and carbon compounds not utilized by the animals for either maintenance or growth and excreted in the feces and /or urine (Carey, et al., 2004; Mutlu, et al. 2005). The release of ammonia from animal manure is dependent upon the amount of ammoniacal nitrogen present, pH, surface area, temperature, and the amount of urease present (Mutlu, et al., 2005; Gay and Knowlton, 2005). Therefore, for any emissions intervention to be effective, it must exploit at least one of these avenues to prevent NH_3 release into the atmosphere (Jongebreur and Monteny, 2001). VOCs are mostly derived from the bacterial degradation of manures soon after excretion (Mitloehner, 2005). Decreasing the bacterial activity in freshly excreted manures should then reduce the production & subsequent emissions of VOCs.

Ammonia emission from animal housing is calculated by multiplying ammonia concentration by airflow. Research and extensive commercial application show that the use of Sodium Bisulfate reduces ammonia emissions two ways: by reducing ammonia flux from the surface of the poultry litter and by reducing ventilation rates. The amount of emissions reduction can be tailored to a specific location by varying the rate, timing, and surface area of SBS application. Other documented benefits are as follow:

- Fuel savings through reduced ventilation
- Improved bird performance i.e. weight, feed conversion, and livability
- Improved animal welfare through better air quality and paw quality
- Reduced respiratory lesions
- Reduced Salmonella & campylobacter incidence of broilers
- Fly control in layer, equine, and calf housing
- Reduction in environmental mastitis
- Substantial return on investment.

Mitigation Mechanism:

Sodium bisulfate (SBS) is a dry, granular acid salt that has been used for many years as a pH reducer in a variety of agricultural, industrial, and food applications. The anti-bacterial properties of sodium bisulfate have been exploited in its application as a toilet-bowl sanitizer (i.e. EPA Reg. #1913-24-AA) and as a preservative in EPA method #5035 "Closed-System Purge-and-Trap & Extraction for Volatile Organics in Soil & Waste Samples," to prevent microbial activity leading to VOC release. These properties along with the safety and ease of use of SBS have led to its use for ammonia binding (Fig.1) and bacterial reduction in poultry, dairy, and equine manure and bedding materials (Ullman, et al., 2004; Blake and Hess, 2001; Sweeney, et al., 1996; Harper, 2002). The use of SBS reduces ammonia emissions two ways: by reducing ammonia flux from the surface of the poultry litter and by reducing ventilation rates. Sodium bisulfate is hygroscopic. As water is adsorbed into the SBS bead from the humidity in the air, the SBS is dissolved into its Na^+, H^+, and $SO_4^=$ constituents.

100 lbs. Of SBS Binds 14 lbs. NH_3						
$2\,NaHSO_4$	+	$2NH_4OH \longrightarrow$	$(NH_4)_2SO_4$	+ Na_2SO_4	+ $2H_2O$
100 lbs.		29 lbs.	55 lbs.	59 lbs.	15 lbs.

Figure 1. Binding of Ammonia by SBS to produce Ammonium Sulfate

The hydrogen ion reduces the pH of the litter and protonates the ammonia molecule. The resulting ammonium is then bound by the sulfate component. This formation of ammonium sulfate is non reversible therefore the nitrogen in the litter is not released as the pH increases (Ullman, et al., 2004). The sodium and hydrogen ions of SBS exert negative pressure on the bacterial populations of the litter; decreasing total aerobic population counts 2-3 logs (Pope and

Cherry, 2000). This may also serve to decrease urease concentration in the litter for additional ammonia reductions (Ullman, et al., 2004). Once the ammonia concentration at bird level has been reduced, the poultry houses can be minimally ventilated for relative humidity control as they were designed rather than over-ventilated for NH_3 removal (Czarick and Lacey, 1998). In an ongoing emissions study being conducted at North Carolina State University, the value of whole house application and higher rates of application of SBS on reducing emissions are being demonstrated. In houses using an industry standard rate of 75-lbs/1000 sqft, emissions from brood chamber only application totaled 32.52 kg-NH3 per house for the 14 day brooding period compared to 23.96 kg-NH3 for a whole house application at the same rate for the same time period. Houses receiving 150-lbs of SBS per 1000 sqft in a whole house application had an average total emission for the 14-day brooding period of only 4.9-kg of ammonia.

Applicability:

Sodium bisulfate is suited to a wide variety of animal housing types. SBS has been used successfully in commercial applications in dry litter in both broiler, turkey, and layer facilities, deep bedding of horses, swine, and cattle, and free-stall and dry lot dairy housing systems. Due to the safety of SBS, it can be broadcast in the presence of animals at any time during production unlike most other amendments. This flexibility allows for each operation to tailor SBS usage rate and application timing to meet its unique needs. Any application scheme of SBS will reduce interior ammonia and ventilation rates, thereby reducing ammonia emissions. Specific application rates and application timing are necessary for reduction of food-borne pathogens and fly control purposes.

Reduction of ambient ammonia levels in broiler housing has been demonstrated in a variety of studies. Ammonia levels were 90% lower post PLT application with an average of 6.2 PPM of NH_3 in the treated houses and 62.3 PPM in the control houses. Two weeks after application, the ammonia levels in the treated houses were still reduced by 50% compared to control houses. Two hundred commercial broiler houses were studied in Delaware and Maryland by Terzich (1997) with 100 houses treated with PLT® and 100 houses serving as control. Ammonia levels averaged 127 PPM pre-treatment and were all 0 PPM post-treatment (Table 1). Consequent to the improved air quality, bird performance was significantly improved in the treated houses with better mortality rates, average weights, average daily gain, and percentage of respiratory lesions at processing compared to controls. Fuel usage was also reported to be 43% less in the treated houses. At a cost of $120/house for the PLT® litter treatment, the resulting production increases and fuel savings provided the producer with a substantial return on investment that would support increased PLT addition rates to maximize ammonia emissions reductions while maintaining producer profitability. Similar ammonia results and improvements in respiratory health through the use of PLT have also been reported (Terzich et al, 1998; Terzich et al, Apr 1998).

Table 1. Average ammonia levels and litter pH values in 100 houses in which litter was treated with sodium bisulfate compared with 100 houses that were untreated controls.

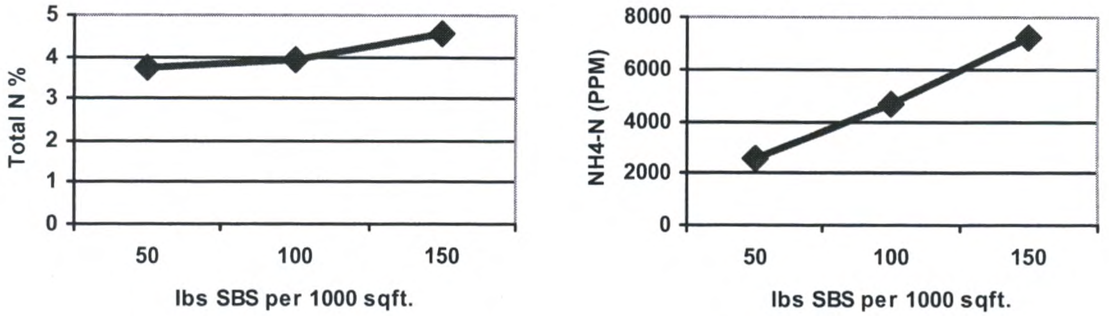
		Pre-Treatment	Post-Treatment	Time (weeks)						
				1	2	3	4	5	6	7
Ammonia (PPM)	Treated	127	0	0	5	8	15	19	20	18
	Control	119	119	125	125	138	114	128	98	97
Litter pH	Treated	8.5	1.7	2.1	3.4	4.5	5.0	5.5	5.9	6.4
	Control	8.9	8.9	8.7	9.1	8.5	9.3	8.6	8.1	8.9

By converting ammonia into ammonium sulfate, the use of SBS increases fertilizer value of litter and displaces phosphorus resulting in improved nitrogen to phosphorus ratio. In a study at the University of Georgia, a linear increase is evident in both N and NH_4-N retained in the litter as the amount of PLT applied is increased (Fig. 3 & 4).

Similar results were observed in a commercial egg layer high-rise house where the higher rate of PLT showed the most consistent decrease in ammonia emissions (Patterson et al, 2006). As in the UGA study, manure ammonium (NH_4^+) nitrogen and P_2O_5 were positively altered by treatment group with the high-rate treatment group having the highest level of retained nitrogen and the lowest level of P_2O_5 (table 2).

Limitations:

Sodium bisulfate is only limited by the amount of product applied. Because of the hygroscopic nature of SBS, greater longevity of ammonia reductions will occur at interior housing humidity of 75% or less. This is consistent with the normal and proper ventilation of poultry houses for relative humidity control.



Figures 3 & 4. Amount of retained Total Nitrogen and NH4-N in broiler litter after three flocks of SBS usage on re-used litter.

Table 2. Commercial Layer Manure Analysis after 8 PLT® treatments over a 45-day period

Treatment	Total N (lbs/ton)	NH_4-N (lbs/ton)	Total Phosphate (P_2O_5) (lbs/ton)
Control	38.37^b	11.08^c	71.63^a
PLT-150	40.50^{ab}	13.75^b	62.38^b
PLT-300	46.08^a	17.06^a	55.48^c
P-value	0.0551	<0.0001	0.0004

Cost:

Multiple field demonstrations of PLT litter amendment use in commercial poultry complexes have also documented the economic benefits of using PLT® litter acidifier. Two field demonstrations completed in 1999 are discussed here.

A commercial broiler complex in the Southeast raising both a large (7.0 lb. or 3.2 kg) and small (4.5 lb. or 2.05 kg) bird evaluated the economic and performance benefits of using litter amendments from January – August 2000. Contract growers were given a choice of either using PLT® or an alum litter amendment (Al+Clear, General Chemical Corp., Parsippany, NJ) at the rate of 2.27 kg/9.29m^2 (50 lbs. /1000 sq ft) in the brood chamber (10,000 sq ft). Eighty-seven percent of the big bird growers and eighty-two percent of small bird growers chose PLT. The remaining thirteen percent of the big-bird and eighteen percent of the small-bird growers chose to use alum in an identical manner to the PLT. A total of 43.9 million birds were evaluated in this demonstration. The variety of housing and management types were similar between the treatment groups. Both the small and large bird groups raised on PLT substantially out performed the birds raised on alum (table3). In a complex of this size, the general rule of thumb used in the U.S. poultry industry is that an improvement in feed conversion of 0.01 lbs. of weight gain / lb. of feed consumption is worth $1 Million per year (Agrimetrics Associates, Inc., Midlothian, VA). The large birds raised on PLT had a feed conversion improved by 0.02 and the feed conversion of the small birds was improved by 0.04 over the birds raised on alum. This reduced performance shown by the birds raised on alum is consistent with production losses due to ammonia exposure reported in the literature (Miles, et al., 2004). This resulted in a net return of $2.7 million /yr over the cost of PLT ($305,000) on improved feed conversion alone in that complex. Additional economic benefit would have also been realized by the grower and the poultry integrator from the increases in weight and livability observed in this trial. Similar results were achieved in another complex in the South-Central part of the U.S. where the same rate of PLT application was compared with untreated litter (table 4). The economic viability of the use of PLT for reducing ammonia emissions is the reason why so many poultry growers have voluntarily adopted this BMP.

Sodium bisulfate costs $0.50/kg ($0.23/lb) and the use of a commercial applicator is approximately $40-45 per house. SBS is safe enough to be applied by the farmer or poultry grower. No additional house preparation is necessary for application. Fuel savings in the first 2-3 days recoup the cost of SBS and its application. Improvements in feed conversion, weight, livability, and paw quality all provide substantial additional return on investment.

Table 3. Production Data from Southeast Commercial Broiler Complex for all flocks raised on either SBS or alum from January-August 2000.

Bird Size	Performance Parameter	SBS	Alum
Large (7.0 lb/3.2 kg)	Total Number of Birds	19, 086, 816	2,846,212
	Livability (%)	88.86[1]	87.66
	Feed Conversion	2.27	2.29
	Weight (lbs)	6.92	6.81
	Condemnation (%)	1.77	2.11
Small (4.5 lb/2.05 kg)	Total Number of Birds	18,091,297	3,869,792
	Livability (%)	93.2	92.06
	Feed Conversion	2.05	2.09
	Weight (lbs)	4.52	4.5
	Condemnation (%)	1.07	1.99

[1] Includes Three flocks with livability <20% due to an ice storm and subsequent roof collapse

Table 4. Production data from South-Central Commercial Broiler Complex for all flocks raised on either SBS or untreated litter from October, 1999-March, 2000.

Performance Parameter	Untreated Control	SBS-Treated
Total Number of Birds Placed	9,101,579	9,921,203
Age (days)	40	39
Weight (lbs)	3.87	3.88
Livability (%)	96.73	96.84
Condemnation (%)	0.34	0.32
Feed Conversion	1.87	1.85

Implementation:

The rate and timing of SBS application are dependent upon the type of housing to be treated, the age of the bedding material in the house, and the age of the animals being housed. Application rates begin at 0.32 kg/m^2 (50-lbs/1000 sqft) for new bedding and litter up to 3-4 flocks old. As the bedding material ages or the manure load increases, the application rate is increased accordingly. Rates of 0.64-0.96 kg/m^2 (100-150-lbs/1000 sqft) are commonly used in commercial field applications. The two drivers of ammonia release from the litter or bedding material are temperature and surface area. Because there is no choice but to have the proper floor temperatures to brood chicks, surface area of the litter particles needs to be minimized to reduce ammonia release from the litter. The amount of SBS needed for a particular grow-out is dependent on the amount of ammonia in the litter and how readily that ammonia is released. The older the birds raised on a farm and the higher the number of flocks raised on the litter, the more fecal material that is present. In other words, 3 flock litter from a house of 45-day-old 1.8-kg birds will have much less ammonia in it than 3 flock litter from a house of 4.2-kg roasters. Also, litter that has been aggressively handled and has maximum surface area will release far more ammonia than litter that has been crusted correctly. Because the amount of amendment used has to be matched to the ammonia load in a particular location, it is important to follow the manufacturer's recommendations when deciding upon the correct rate to use for a specific location and animal type.

In poultry housing, SBS is routinely applied prior to bird placement using a broadcast spreader of some type. Both professional application with a truck mounted spreader and hand application with a push spreader are used depending on farmer preference. Applications in the presence of animals are often done for bacterial or fly control purposes. Because of the safety and efficacy of SBS, producers have maximum flexibility to meet their needs.

Technology Summary:

Sodium bisulfate reduces ammonia and VOC emissions from animal housing areas. SBS binds ammonia converting it to ammonium sulfate thereby retaining nitrogen and increasing fertilizer value of the litter. Total phosphorus is reduced through dilution. Fuel savings and increased animal performance and welfare are realized allowing the mitigation to pay for itself. Research and commercial field studies indicate a 60-90% reduction of ammonia flux form the bedding surface. Application rates vary from 0.32-1.95 kg/m2 depending on the litter age and concentration of manure in the bedding. Sodium bisulfate costs $0.50/kg ($0.23/lb) and the use of a commercial applicator is approximately $40-45 per house. SBS is safe enough to be applied by the farmer or poultry grower. No additional house preparation is necessary for application. Fuel savings in the first 2-3 days recoup the cost of SBS and its application. Improvements in feed conversion, weight, livability, and paw quality all provide substantial return on investment. Additional benefits include reduced incidence of food-borne pathogens, fewer respiratory lesions and ascites, and improved paw quality.

Additional Resources:

SBS & Horses http://www3.vet.upenn.edu/labs/equinebehavior/publixs/Papers/96effect.pdf
Ammonia & Foals http://animalscience.ag.utk.edu/horses/pdf/foalammo.pdf
Sodium Bisulfate as a Litter Treatment http://www.aces.edu/pubs/docs/A/ANR-1208/

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
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Iowa Pork Industry Center
Iowa Pork Producers Association
U.S. Pork Center of Excellence

Using Klasp™ to Reduce Poultry Housing Ammonia Emissions

L. Reeder and V. Johnson
Kemira

Species: Poultry (Broiler, Chicken, and Turkey)
Use Area: Animal Housing
Technology Category: Chemical Amendment
Air Mitigated Pollutants: Ammonia

Description:

Poultry producers traditionally use ventilation and acid-based litter amendments to lower pH, bind litter nitrogen, sequester phosphorus, and dry the litter cake. With respect to ventilation, energy costs increase as ambient temperature decreases. While acid-based litter amendments can be effective for the short- term control of ammonia (NH_3), this effect is typically short-lived in the broiler house environment. The use of litter amendments should provide the poultry producer a net benefit, by providing lower mortality, in-house ammonia control and energy savings, while meeting all environmental goals of the producer.

In-house air quality is a major concern in poultry production. Producers spend much of their time and investment in maintaining good air quality to maximize poultry growth and performance. Previous studies have correlated negative bird performance with poor indoor air quality due to NH_3 volatilization and dusts, (Kling and Quarles, 1974; Charles and Payne, 1966; Anderson et al., 1964; Quarles and King, 1974) and has implicated NH_3 as a component of poultry welfare (Kristensen and Wathes, 2000).

In a series of recent studies conducted by Casey W. Ritz at the University of Georgia, a new type of litter amendment utilizing proprietary ferric sulfate compounding has shown to be an effective litter amendment for minimizing ammonia concentrations, decreasing apparent litter moisture, and at the same time sequestering nitrogen and phosphorous. This product sold under the trade name Klasp™ is predominantly (Fe^2 $(SO_4)^3 \cdot NH_2O$) a dry, granulated form of ferric sulfate that contains approximately 20% iron as Fe_3.

This presentation will discuss the results of four demonstrations conducted in the summer, fall, and winter of 2007. The discussion will include NH_3 reductions in the broiler house, litter characteristics including nutrient levels and moisture, as well as the economics surrounding the use of the amendment. The purpose of this study was to evaluate the effectiveness of Klasp™, a new litter amendment, versus a commonly used alum-based litter amendment.

Mitigation Mechanism:

Ammonia (NH3) concentration in poultry houses is a production issue that causes much concern for producers. Studies of birds housed in environments with NH3 present have not performed as well as birds not exposed to NH3 (Miles et al., 2004). Ventilation has been the primary method of removing and controlling NH3 from poultry houses. However, poultry producers also apply litter treatment products that lower pH, bind nitrogen (N), and dry the existing litter cake. The effects of ammonia and ammonia concentration in poultry houses were studied and documented in multiple houses (Ritz et al., 2006). Research on ammonia in poultry have shown the negative effects on bird health and bird performance when exposed to ammonia levels of 25 parts per million (ppm). Elevated ammonia levels lead to a diminished respiratory system, inducing low growth weights, low feed utilization rates, and high mortality rates. These factors and losses can be linked to the quantities of ammonia and ammonia compounds produced in the poultry house (Miles et al., 2004).

Ammonia is a water soluble, colorless, alkaline gas produced by microbial decomposition of nitrogenous compounds. Litter pH factors heavily in NH_3 volatilization. The application of litter amendments to reduce the pH of the litter is fundamental in the management of ammonia concentrations. Factors that influence litter amendment use are prolonged litter reuse, increased bird density, animal-related stress, disease, and short layout periods. Ammonia produced from poultry litter by the breakdown of uric acid can be inhibited if converted to $NH(^4)(+)$ (ammonium), which can be accomplished by lowering litter pH. The amount of ammonia emitted as NH_3 from the litter is reduced because of these reactions.

Applicability:

Klasp™ (Fe^2 $(SO_4)^3 \cdot NH_2O$) is a dry, granulated form of ferric sulfate that contains approximately 20% iron. Klasp™ is a nontoxic and nonhazardous substance classified as a GRAS (Generally Regarded as Safe) substance to be used by the poultry industry in pursuit of best management practices. As a best management tool Klasp™ effectively reduces ammonia, sequesters phosphorous and nitrogen and efficiently lowers litter pH while providing a drier house environment. These factors provide an improved bird environment and enhanced overall general animal health.

Limitations:

Klasp™ is generally recognized as safe. Klasp™ is an acidic product; therefore appropriate measures should be used during handling. Gloves, a long sleeved shirt, and long pants should be used for the period of product application. A dust mask should be worn to prevent dust inhalation, and goggles worn for eye protection.

Cost:

Cost is dependent on several factors. The producer's proximity to the chemical distributor, application rate, and use cycle of Klasp™ will contribute to the final per house cost.

Implementation:

A rate of 45 kilograms per 93 m2 (100 pounds of Klasp™ per 1,000 ft2) of floor space is the typical recommendation for the treatment of broiler litter (32 kilograms during warm weather production). For most broiler houses, this will equal 680 to 907 kilograms (1500 to 2000 lbs) of Klasp™ per house for each grow-out. A rate of 45 kilograms per 93 m2 (100 pounds per 1,000 ft2) will lower ammonia production. Rate selection for each operation will depend on current management practices and needs, based on factors such as litter reuse, short layout periods, ventilation control, and existing litter moisture levels. Klasp™ can also be safely applied with birds in the house to address management issues that occur post-placement.

Prior to the application of Klasp™, poultry houses should be decaked or rototilled. Klasp™ can be applied up to four (4) days prior to bird placement. Broadcast spreading (cyclone or PTO spreader) is recommended as a litter top coat and incorporation into litter is not required.

Research has shown Klasp™ provides cost savings as a result of reducing the heating and ventilation costs normally associated with the use of litter treatments. There are no heating requirements for material activation prior to bird placement. The activation advantages provided by Klasp™ allow producers application flexibility and improved time management before bird placement. Klasp™ is activated by moisture not heat thus providing time flexibility and energy savings.

The integration and activation of Klasp™ with litter moisture promotes drier houses and extended product activity. With efficient horizontal penetration and coverage you can expect greater surface area impact per granule. Klasp™ provides increased activity and a longer residual effect when compared with other treatments. The highly deliquescent form of Klasp™ is easily spread and its non-clumping grains dissolve quickly providing superior performance in addition to enhanced bird welfare. Klasp™ has substantially less dusting during application leading to a lower impact on labor and does not corrode or adversely effect production equipment.
Klasp™ was, on average, superior to the control litter amendment in reducing NH3 emissions and concentrations in the houses during the first 10 to 12 days after bird placement. Klasp™ also significantly improved retention of nitrogen in the litter over the standard treatments, suggesting that there is an enhancement effect on nitrification of NH4 to the more stable NO3 form (Ritz et al., 2006).

Technology Summary:

In conclusion, University trials and field testing have proven that poultry litter treated with Klasp™, have resulted in:

- Lower house ammonia levels
- Lower litter pH levels
- Drier houses with extended product activity and performance
- Reduction in ventilation requirements and auxiliary heat consumption
- Increased nitrogen content and improved litter value
- Excellent residual performance
- Enhanced application flexibility and time management

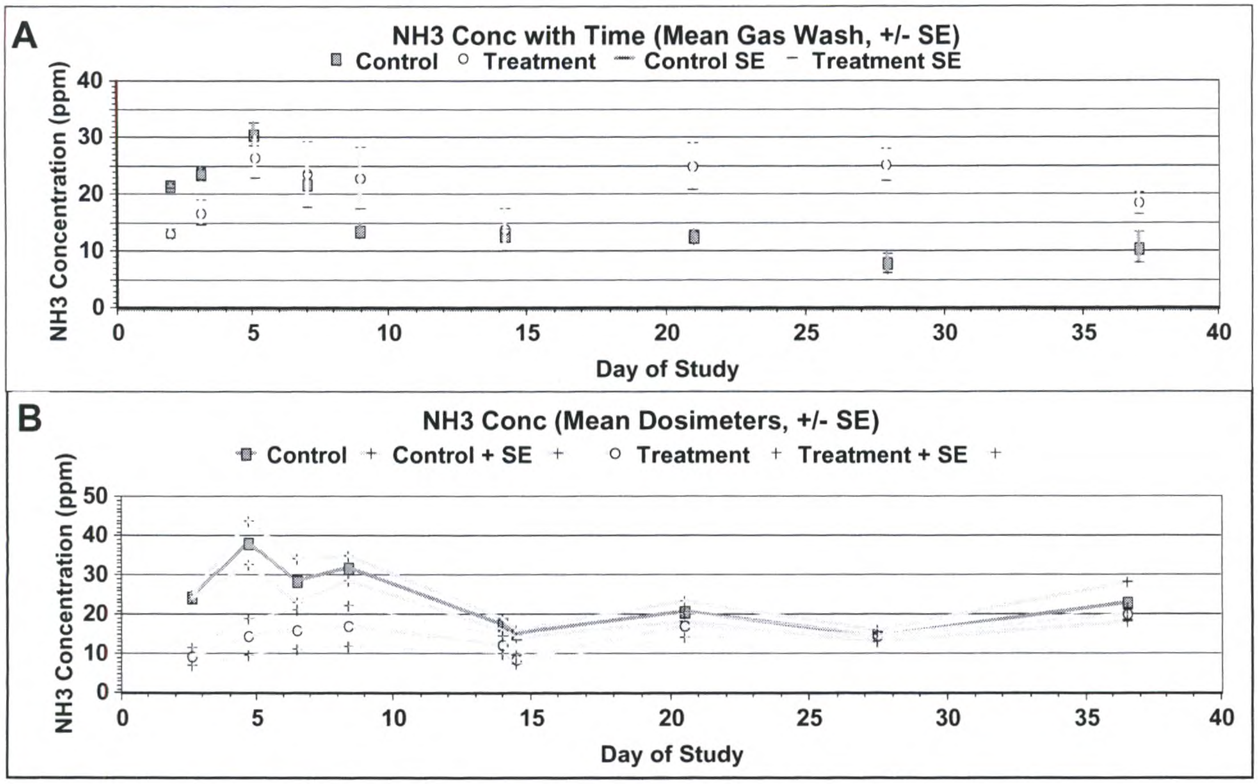

Figure1. Ammonia (NH_3) concentrations in houses treated with alum (control) and Klasp™ (treatment), plotted with standard error bars.

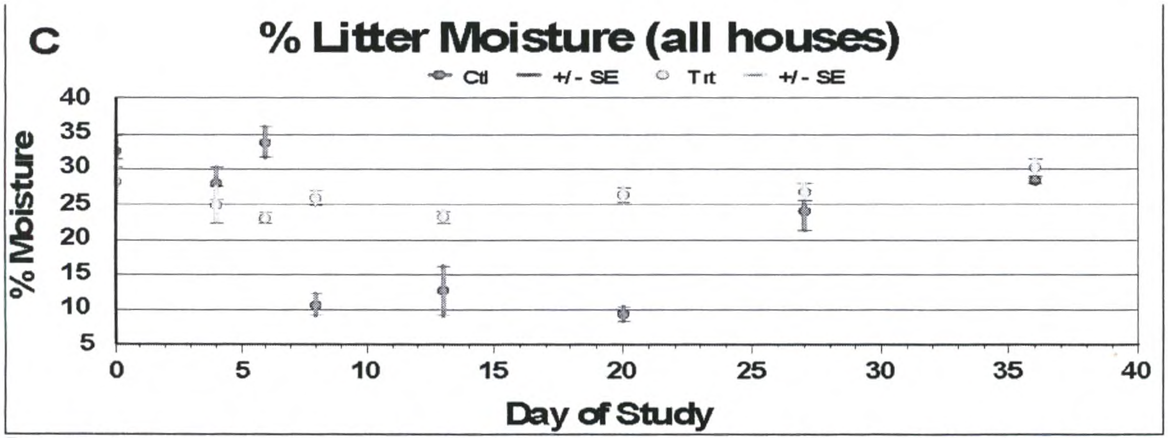

Figure 2. Ammonia (NH_3) concentrations estimated using dosimeter tubes and litter moisture content in the Control (Houses #1 and 2) and Treatment (#3 and 4) houses. Averages are the means of Control and Treatment houses.

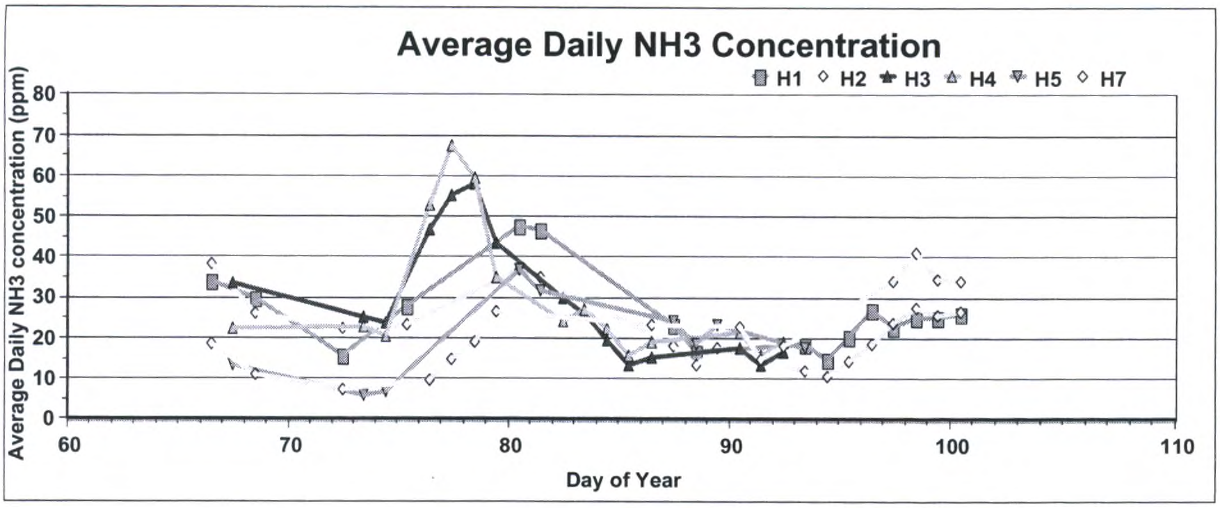

Figure 3. Ammonia (NH_3) concentrations of alum-treated houses (H1, H3, H5) and Klasp™ treated houses (H2, H4, H7).

Table 1. Phosphorus analysis of alum and Klasp™ treated litter. Samples were taken before treatment application and after the broilers were processed.

	Molybdate Reactive Phosphorus (ortho- phosphate)			Total Dissolved Phosphorus		
	Pre-treat (ppm)	Post-treat (ppm)	P-value	Pre-treat (ppm)	Post-treat (ppm)	P-value
Alum Litter	3968	3996	0.466	4854	5166	0.110
Klasp™ Litter	3204	3893	0.015	4096	5081	0.002

References:

Miles, D.M., Branton, S.L., Lott, B.D.2004. *Atmospheric Ammonia is Detrimental to the Performance of Modern Commercial Broilers.*

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
U.S. Pork Center of Excellence
Iowa Farm Bureau Federation
Iowa Egg Council
Iowa Pork Industry Center
Iowa Pork Producers Association

Microbial Additives to Reduce Ammonia Emission from Poultry Houses

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Species: Poultry
Use Area: Animal Housing
Technology Category: Biological Amendment and Diet Modification
Air Mitigated Pollutants: Ammonia

Description:

Intensive and sustainable animal production is very crucial for agricultural based economies. Gaseous ammonia is a byproduct of animal production that has to be managed for the well being of the animals and the environment. Various chemical amendments have been used to minimize ammonia gas release (Arogo et al., 2001) Excessive ammonia levels compromise bird health and the health and safety of workers in the poultry environment (Carlile 1984). The handling and storage of manure generated from layers has become a major concern and in some cases a major expense for layer producers. The application of large amounts of raw poultry manure to fields is thought to contribute to odors and other environmental concerns. Treatment methods such as composting can be used to reduce the odors, pathogenic bacteria and insect eggs thereby improving the economic value of the final material. However, at present only a small percentage of all layer producers compost their manure. Composting is a biological process that requires the carbon nitrogen ratio, moisture, microbial populations and aeration all be in the proper proportions to initiate the aerobic process and produce an acceptable end product. Poorly composted layer manure does not reach and maintain high temperatures and thus requires much more time to complete the process. Slow, extended compost periods also tend to result in higher concentrations of offensive odors and ammonia. In most manure composting management plans, the microbial population is secondary and receives little or no attention. However, the types and numbers of microorganisms determine the extent and efficiency of the compost process which significantly influences the characteristics of the end product.

Mitigation Mechanism:

Gram negative bacteria are highly prevalent in poultry litter and waste. These Gram negative bacteria convert uric acid in the poultry waste to make harmful ammonia. Application of MicroTreat P® to poultry litter lowers the gram negative counts in the litter and poultry waste. The reduction in Gram Negative bacterial population helps in nitrogen retention and reduced ammonia production. *Bacillus* based feed additives Provalen is efficacious and effective to improve performance and reduce ammonia. It also improves odors and other handling and processing problems of layer manure and provides a significant benefit to layer producers. *Bacillus* are sporeforming organisms. Spores are very resistant to environmental stress such as heat and contact with minerals. Therefore, the product will be stable in feed and premixes. The field trials indicate that feeding a *Bacillus* product to layers improves the decomposition process of the manure and provides evidence for the successful direct fed microbial feed additive using *Bacillus*.

Applicability:

Ammonia reduction interventions using microbial products are suitable and safe in all animal production systems. It is also specially suited for poultry production facilities that are computer controlled to allow for air exchange. MicroTreat P® is a biological litter treatment product that utilizes the activity of specifically selected bacteria to control the gram-negative microorganisms in poultry litter. MicroTreat P® is effective in reducing the level of gram negative bacteria present in poultry litter. Gram negative bacteria are known to have detrimental effects upon bird health due to the fact that many avian pathogenic bacteria are classified as gram negative. Besides this direct effect upon bird health, gram negative bacteria also indirectly reduce performance by negatively impacting the bird's environment. Gram negative bacteria have the ability to break down the uric acid excreted by poultry and convert it to the end product of ammonia. As is well documented, high ammonia levels decrease bird health and performance and also can be a health hazard for farm workers. Regulations restricting ammonia emissions are also in the near future for agricultural companies. Because MicroTreat P® reduces the poultry litter gram negative bacterial population, there are less gram negative bacteria present to break down the uric acid and produce ammonia. MicroTreat P® is applied to the litter either directly or through the drinking water. The timing of the application is at the beginning of the production phase, brooder or finisher, and is a one time application for each phase.

Research with MicroTreat P® has consistently shown a 50-90% reduction in total gram negative bacterial litter levels. The reduction of gram negative bacteria has been correlated in an improvement in production cost of $0.0055 / lbs.

This cost savings has been demonstrated in paired house testing up to large field trials and entire integrator usage that resulted in 1000's of flocks being tested. The reduction of ammonia with the use of MicroTreat “P” has been well documented within several poultry integrators. MicroTreat P®” use typically results in a 40-60% reduction of in-house ammonia levels.

Limitations:

There are no known limitations of this technology. The bacterial organisms are listed as GRAS (Generally Regarded As Safe). Unlike chemical amendments, microbiological additives work in the animal production environment reducing the cumulative ammonia emission.

Cost:

MicroTreat P comes in foil packs and is concentrated for convenient use. The application rate is based on type of poultry and fecal material produced. Typically the treatment costs are as follows: Broilers $0.005 per bird, Turkeys $0.055 (40 pound tom) and $0.028 (16 pound hen). The cost to treat layers feed with Provalen is approximately $2.00/ ton.

Implementation:

Provalen is a *Bacillus* based feed additive that utilizes the enzyme producing activity of specifically selected strains to enhance performance, control manure decomposition and thus reduce ammonia and odors associated with the storage of poultry manure. The Provalen *Bacillus* strains were selected on their ability to produce proteolytic and amylolitic enzymes. Feeding trials have consistently demonstrated a 30-50% reduction in the level of ammonia in laying production facilities. Also seen in these studies was an improvement or retention of nitrogen values in the manure produced by the laying hens of approximately 15%. A feeding study demonstrated the ability of Provalen to improve the feed efficiency of laying hens without reducing overall egg production. There was observed benefits for shell quality, as measured by a reduction in cracked eggs, an increase in large egg production and improvements in overall feed efficiency that resulted in an annual $0.019 per hen housed net return with Provalen use. This study is being combined with field data demonstrating reductions in the levels of ammonia in production facilities.

Technology Summary:

Future Environmental Regulations will force the animal production industry to find new interventions that will provide improvements in the decomposition of stored manure. A by product of the decomposition of stored manure is ammonia. Ammonia will play a key role in the regulation of confined animal facilities. Commercial products will need to be targeted to lower the level of ammonia in the confined animal facilities and more importantly, lower the overall amount of ammonia that is generated at each facility. Regulations will be based upon total production of ammonia from each facility. In addition, regulations will also include other compounds (gases, odors) emitted from confined animal feeding operations. Agtech possess a portfolio of products and bacterial species (Bacillus and Propionibacteria) that alter ammonia formation and have efficacy in the area of ammonia and odor production.

References:

Arogo, J., P.W. Westerman, A.J. Heber, W.P. Robarge, and J.J. Classen. 2001. *Ammonia in Animal Production*. ASAE Paper No. 014089, Sacramento, CA.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
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Effects of Aluminum Sulfate and Aluminum Chloride Applications to Manure on Ammonia Emission from a High-Rise Layer Barn

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Species:	Poultry (Layer)
Use Area:	Animal Housing
Technology Category:	Chemical Amendment
Air Mitigated Pollutants:	Ammonia

Description:

High concentrations and emission rates of ammonia (NH_3) are a major air quality concern for modern and large layer facilities. However, very few studies have been conducted to systematically quantify NH_3 emission from such facilities, while even fewer have reported the effects of whole-barn emission mitigation strategies. Practices to reduce NH_3 emission include diet manipulation, manure drying, frequent manure removal, and manure amendment.

The effectiveness of aluminum sulfate (alum, $Al_2(SO_4)_3$) as a litter amendment in broiler houses has been proven in both lab-scale experiments (Moore et al., 1995) and field tests (Armstrong et al., 2003; Worley et al., 1999). The addition of alum to poultry litter reduces NH_3 volatilization; increases total and soluble N in the litter, which in turn increases N/P ratios; reduce fuel (heating) costs; and lowers in-house NH_3 concentrations. Alum application also potentially improves bird health and reduces phosphorous runoff. However, there have been no studies of alum and aluminum chloride ($AlCl_3$) applications in commercial size, high-rise layer barns. There are significant differences between layer and broiler houses. The major differences are that in high-rise houses: 1) manure is stored without litter, 2) the manure is stored on the first floor out of reach of the birds, 3) a significant amount of fresh manure does not reach the manure storage for several hours, and 4) manure is stored for much longer periods. Therefore, a full-scale test in a layer barn was needed to study the effectiveness of alum and $AlCl_3$ in reducing ammonia emissions.

Mitigation Mechanism:

Large amounts of manure are stored in the first floor of high-rise layer barns for up to one year. Ammonia emissions from these barns can therefore be significant, and are affected by factors such as manure management, manure drying strategies, diet, and geographical location. Nutrients are released from manure by microbial processes into forms that can be taken up by plants or emit into the environment. Nitrogen is released as ammonium (NH_4+) under acidic or neutral conditions, or as NH_3 at higher pH levels. Applying acidifying agents to reduce manure pH values can be an effective method to reduce NH_3 volatilization. Alum was identified as an economical agent to reduce NH_3 volatilization and the amount of soluble phosphorous in the manure (Moore et al., 1995).

Applicability:

Either dry or liquid alum can be used to amend manure pH, but the additional water associated with liquid alum can increase manure moisture content, which tends to increase ammonia release. Ammonia concentration and emission rate in layer barns is much larger if the manure moisture content is not minimized. Alum application between growth cycles when broiler houses are empty was proven effective in reducing broiler house NH_3 emissions (Worley et al., 2000). Alum applications in high-rise layer barns are much less convenient and there are several reasons the same success of alum in broiler houses may not be realized in layer houses. Layer manure is: 1) not mixed with litter, 2) stored in large piles on the first floor, 3) sometimes on the second floor for several hours before being scraped into the first floor, 4) stored in the barn for 4 to 8 times longer than broiler manure. Because of the existing untreated pile of manure at the beginning of the test, dry alum was manually applied initially, and an automated spraying system was used to regularly apply liquid alum in the treated barn.

The ammonia mitigation tests were conducted at two 169,000-hen capacity high-rise layer barns in Ohio. The tests were conducted to evaluate baseline and mitigated emission rates. The test was conducted at the site of a six-month particulate impaction system test (Lim et al., 2005). A spraying system for applying alum and $AlCl_3$ was installed in the treated Barn 2. Concentrations were measured at the barn exhaust fans and in incoming air, using well-maintained and -calibrated online ammonia analyzers. Other measured variables included temperatures, relative humidity, building static pressure, and fan operation.

The mean untreated NH_3 emission rate was 480 g/d-AU (1.35 g/d-hen), where AU is an animal unit or 500 kg (1100 lb) of bird weight. The alum and $AlCl_3$ applications reduced NH_3 emission by 23%, based on the NH_3 emission differences between barns, Figure 1. Mitigation efficiency of the alum application was compromised by clogged nozzles, manure turning, and the introduction of a new flock of hens. Higher reductions of 33, 23 and 40% were achieved during later test periods. The application of $AlCl_3$ in the last test was expected to further reduce NH_3 emission, but the reduction was only 27%, which was probably due to the higher moisture content of manure in Barn 2.

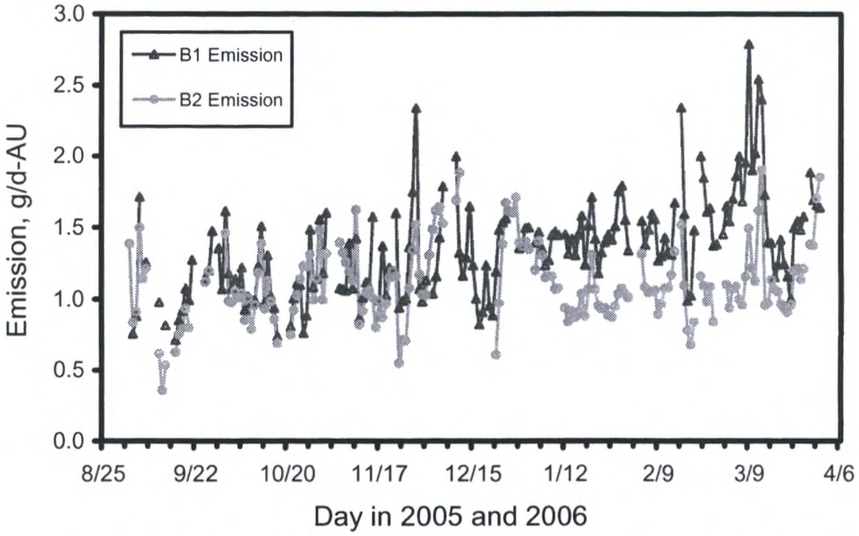

Figure 1. Daily mean NH_3 emissions of untreated Barn 1 and treated Barn 2.

Limitations:

Application of dry alum was not economically feasible because of higher costs. Results indicated that since manure moisture content (in percentage) ranged from the upper 20s (warm months) to the upper 30s (cold months), the amount of liquid alum that can be applied is limited. The additional chemical solution from frequent spraying and flushing the system with water had increased manure moisture content, especially in cold weather, thus reducing mitigating effectiveness.

The nozzles were easily clogged by alum salt accumulation, thus requiring frequent maintenance and cleaning. The automated spraying system required training to operate and maintain. Furthermore, the chemicals were acidic and corrosive, making it more difficult to check for spraying efficiency during system operation. The spraying area was also limited to avoid damaging the manure drying fans in the pit, and was not applied in the area along the side walls where barn ventilation fans were located.

The major limitation is related to the fact that manure that is on the second floor is not treated. Since NH_3 release from manure decreases exponentially after excretion, the second floor manure emits more NH_3. Previous studies have shown that approximately 50% of a high rise barn's ammonia emissions are from the second floor and 50% are from the first floor. Therefore, the theoretical limit of the potential reduction of alum application to the first floor is only 50%.

Cost:

The costs of the alum and $AlCl_3$ were \$0.13/L and \$0.14/L, respectively, without delivery charges. At each delivery, 5678 L (1500 gal) of alum or $AlCl_3$ was first added into the holding tank, and an equal volume of water was added to produce a 50% solution. The field records showed that five deliveries worth \$3700 of alum were used in 85 days, or \$44 per barn per day. The automatic spray controller cost about \$3000, and the doubled-wall holding tank was \$6500. A single wall tank would be less expensive. The labor to maintain the controller, air and water pumps is estimated at 3 hours per week per barn. The air pump provided the pressure for spraying, and the water pump filled the spray pipe with the solution.

Implementation:

Several tests were conducted during the seven month alum and $AlCl_3$ test. The tests were conducted in conjunction with tests of the Electrostatic Space Charge System (ESCS) (Lim et al., 2008). Both the ESCS and alum tests were conducted in B2, while B1 served as the untreated (control) barn. The test schedule and descriptions are listed in Table 1. A total of six tons of dry alum were manually sprayed onto the manure surfaces before the alum solution spraying was started. The application of dry alum was about 1.4 kg/m^2 of manure surface. An 11,360-L (3000-gal) holding tank was used to store the chemicals, while spray tubes and sprinkling nozzles were installed along the barn length. Solutions were sprayed for four seconds every hour. .The Alum spraying system and ESCS operated simultaneously between September 29, 2005 and January 20, 2006 (Test 4).

Table 1. Tests conducted during study.

Test	Date	Description	Emission difference
1	9/1-9/10	ESCS	11%
2	9/11-9/20	Alum	29%
3	9/21-9/29	ESCS	12%
4a	9/30-11/4	ESCS + alum, some nozzles were clogged	16%
4b	11/5-12/12	ESCS + alum, nozzles were cleaned on 11/4	16%
4c	12/22-1/20	ESCS + alum, new hens in B2, nozzles cleaned (1/12)	17%
5	1/21-2/9	ESCS + alum (A7, single dose)	33%
6	2/10-2/15	ESCS + alum (A7, 1.5 dose)	23%
7	2/16-3/7	Alum (A7, 1.5 dose) + evening manure scraping*	40%
8	3/8-3/31	Aluminum chloride + evening manure scraping	27%

* ESCS operation was discontinued on March 4, 2006.

Many nozzles were clogged by alum salt accumulation during Test 4, and had to be removed and cleaned. Other maintenance included replacing the alum spraying pump and flushing nozzles with water to prevent clogging. Barn 2 was emptied on December 13, and was restocked with new birds on December 17. The original alum was replaced with a new formula ("A7") on January 21 (Test 5). Application rate was increased by increasing the spray time for Test 6. The manure scraping schedule was changed from morning to evening for Test 7, to reduce the amount of time that manure produced during the day was left untreated on the second floor. Aluminum chloride was applied in Test 8. It was assumed that the ESCS did not significantly affect the abatement efficacy of alum and AlCl3 on NH3 emissions.

The mean NH3 emission rates were 403 and 365 g/d-AU for B1 and B2, respectively, before the alum spraying was started. The overall average emission rates during the alum tests (Tests 2 and 4 to 8) were 483 g/d-AU for B1 (control) and 369 g/d-AU for B2. The Test 3 emission rates were excluded in the comparison because it was assumed that the residual alum from Test 2 continued treating the manure during Test 3 after the Alum application was discontinued.

The overall paired emission differences between the two barns were 11% and 23% for the control test period (Test 1) and the experiments (Tests 2 and 4 to 8), respectively. Since the B2 NH3 emission rate of Test 1 was 11% (mean of 4 paired emission rate differences) lower than B1, the overall reduction of 23% due to alum and AlCl3 applications may be slightly lower. However, the 11% difference in Test 1 was calculated from a small number of paired emission values, and lasted only 10 days in September, which is a very small portion of the seven-month test, thus the barn difference before the treatment was not used to correct or adjust the reductions in subsequent tests.
The mean NH3 emission rates of Test 2, when the dry and alum solution was first applied, were 321 and 213 g/d-AU for B1 and B2, respectively. It was apparent that the B2 NH3 emission rate was reduced by alum application as the mean paired B2-B1 emission reduction was 29% (n=7 out of 10 d). In Test 4, the ADM NH3 emission rates were 447 and 379 g/d-AU for B1 and B2, and the mean paired difference was 16% (n=31 d, September 30, 2005 to January 20, 2006). The lower NH3 emission reduction in Test 4 was probably due to the clogged nozzles, manure turning activities, and the lack of a layer of alum as compared with Test 2. The clogged nozzles reduced the alum application rate and the total area of alum-treated manure surfaces, thus lowering the emission reduction. The more frequent manure turning may have destroyed the protective layer of alum. This is especially true when a significant part of the NH3 emission was expected to be generated by the newly scraped, fresh manure on the surfaces of the piles. The lower reduction at the end of December (Test 4c) was probably caused by the new flock of hens in B2, in addition to the many clogged nozzles. After the flock adapted to the new environment, and more than 40 nozzles were removed and cleaned, the paired NH3 emission differences averaged 35% (n=8) for January 13 to 20, 2006.

The mean NH3 emission reductions were 33%, 23%, 40%, and 27% for Tests 5 to 8, respectively. The highest paired NH3 emission reductions were observed in Tests 5 and 7, which were probably due to the combined effects of well-functioning nozzles, evening manure scraping, and application of the A7 alum. Due to the lack of test replication and only one treated barn, it is not known which factor contributed the most. The emission rate differences between the two barns averaged 32%, and ranged from -10% to 52% between January 21 and March 31.

The mean NH3 emission rates were 583 and 415 g/d-AU for B1 and B2 in the test of AlCl3 (Test 8). The abatement effect of AlCl3 appeared to be lower than alum, but the lower reductions were probably caused by the higher manure moisture content in B2. Manure in B2 was observed to be wetter at the end of the tests, most likely due to the amount of moisture from increased spraying rate and additional flushing water from cleaning the spraying system. Manure with higher moisture content was expected to release more NH3 than drier manure piles. The other important factor was the lower barn ventilation rate in the colder months. The mean barn airflow rates were 242, 57, and 81 m^3/s during Tests 2, 7 and 8, respectively. Since barn airflow was over 70% lower in the colder months, the extra moisture applied onto the manure surfaces was probably not removed as efficiently in the warmer months. Manure moisture content and pH values are reported in Figure 2.

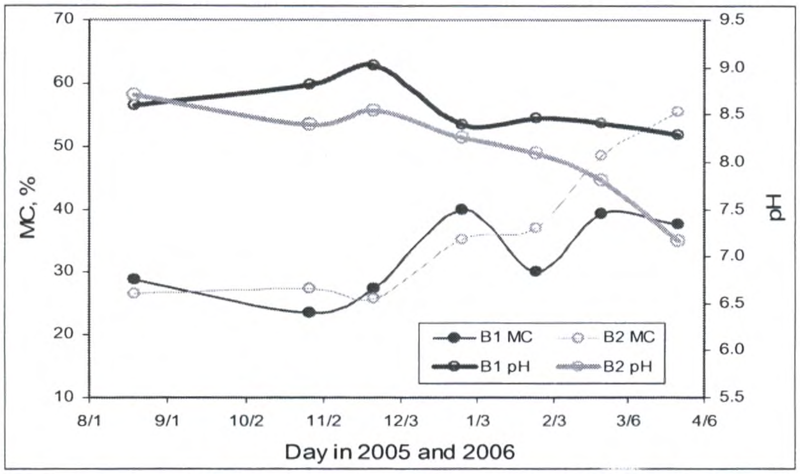

Figure 2. Mean manure moisture content and pH values of untreated Barn 1 and treated Barn 2.

Technology Summary:

Dry alum, and liquid alum and $AlCl_3$ solutions were applied in a high-rise layer barn to reduce NH_3 emission. Dry alum was manually applied at the beginning of the test, while the solutions were automatically sprayed every hour. The alum application reduced NH_3 emission rate by 29% when dry and liquid alum were first applied. The alum and $AlCl_3$ applications reduced NH_3 emission by 23%, based on the overall cross-barn comparison of paired NH_3 emission rates.

The NH_3 mitigation efficiency of the alum application was compromised by clogged nozzles, manure turning, and introduction of a new flock of hens. Higher reductions of 33%, 23%, and 40% were achieved in Tests 5 to 7. The efficacy of the alum spraying was the highest from January 21 to March 7, 2006, when the nozzles were well maintained, manure turning was discontinued, application rate was increased, and daily manure scraping was switched from morning to evening. The paired emission rate differences between the two barns averaged 32%. The application of $AlCl_3$ was expected to further reduce NH_3 emission, but averaged only 27% in Test 8, which was probably due to higher moisture content of manure in B2.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
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U.S. Pork Center of Excellence

Reducing Ammonia Emissions from Poultry Litter with Alum

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Species: Poultry (Broiler Chicken and Turkey)
Use Area: Animal Housing
Technology Category: Chemical Amendment
Mitigated Air Pollutants: Ammonia

Description:

Ammonia emissions from poultry manure can cause several problems. Often ammonia concentrations in poultry rearing facilities reach very high levels, causing poor poultry performance (Carlisle, 1984). Anderson et al. (1964) showed that ammonia levels as low as 20 ppm compromised the immune system of chickens, making them more susceptible to diseases and damaged the respiratory system of the birds. Feed conversion and weight gains in poultry are also affected by high levels of ammonia (Carlile, 1984). As a result of all these negative impacts on performance, Carlile (1984) recommended ammonia concentrations in poultry barns be kept below 25 ppm. High levels of ammonia may also pose a risk to the health of agricultural workers in these facilities (Donham, 2000). In addition, ammonia releases from poultry facilities into the atmosphere can cause environmental problems, such as acid precipitation, fine particulate matter formation (particulate matter with an aerodynamic diameter less than ten microns in size), and nitrogen deposition into aquatic systems.

Because of the negative impact of high levels of ammonia on poultry growth (particularly at an early age), poultry growers often use litter amendments, such as dry or liquid acids, to reduce ammonia volatilization. Moore et al. (1995, 1996) found that aluminum sulfate (commonly referred to as alum) was more effective than other litter amendments for ammonia control. Subsequent work by Moore et al. (1999, 2000) showed that alum additions to commercial broiler houses reduced ammonia emissions for about four weeks, resulting in heavier birds with better feed conversion, lower mortality, and lower condemnation.

Benefits of treating poultry litter with alum include the following (Moore et al., 2003):

- Reduced ammonia levels improve bird performance and make a safer workplace (Moore et al., 2000, 2008),
- Lower litter pH results in reduced pathogen levels in the litter and on bird carcasses (Lines, 2002),
- Lower propane use during winter as a result of reduced ventilation for ammonia control (Moore et al., 1999),
- Reduced phosphorus runoff and leaching (Moore et al., 1999, 2000; Moore and Edwards, 2006),
- Reduced levels of heavy metals and estrogen in runoff (Moore et al., 1998, Nichols et al., 1997), and
- Crop yields are higher because alum-treated litter contains more nitrogen (Moore and Edwards, 2005).

Mitigation Mechanism:

Ammonia volatilization from manure is dependent on several variables, including manure pH, temperature, moisture content and in-house air velocity. Typically, untreated poultry litter has a high (basic) pH; often above 8. At this pH a large percentage of the inorganic nitrogen in litter is in the ammonia (NH_3) form. This form can become a gas and volatilize from the litter. When alum is added, it lowers the litter pH (makes it more acid) by providing a source of acidity or hydrogen ions (H^+), which react with ammonia to form ammonium (NH_4^+). Since ammonium is not volatile, the amount of ammonia emitted from the litter decreases. As long as the litter pH stays relatively low (less than about 7), ammonia emissions are controlled. The length of time the poultry litter pH is reduced and ammonia is controlled is dependent on the rate of alum used, with higher rates resulting in a longer period of ammonia control (Moore et al., 2008). The acidity generated by alum applications (lower litter pH) is also responsible for reduced pathogen numbers in alum-treated litter. Phosphorus runoff and leaching are decreased with alum because the aluminum from alum binds with phosphorus in the litter to make an aluminum phosphate compound which is far less subject to runoff or leaching.

Applicability:

This best management practice applies to all poultry operations that have dry litter (broiler, breeder and turkey houses). Typically alum is applied to litter between each flock of birds. If phosphorus control is desired, then the alum should be tilled into the litter to get good interaction of aluminum and phosphorus. There are three forms of alum that are commonly used; dry alum, liquid alum (48.5% alum) and high acid liquid alum (36.5% alum). High acid liquid alum is preferred in situations were the litter is very dry, since it activates quickly, whereas dry alum is definitely preferred when litter moisture contents are higher. The two forms of liquid alum must be applied by a certified professional applicator, while dry alum may be applied by anyone.

Additions of alum to poultry litter, particularly at higher rates, has been shown to reduce ammonia concentrations by over 75% for the first two weeks of the flock, 50% the third week, 20-30% thereafter (Table 1). Addition of dry alum at the high and low rates reduced average weekly ammonia emissions by 47 and 35%, respectively, compared to the control barns (Table 2). The low rate of liquid alum only reduced average weekly NH_3 emissions by 26%, which indicates that dry alum is probably more effective. The ammonia concentration data reported here are similar to that reported by Moore et al. (2000), however, the reduction in ammonia emissions was not as great as found in earlier work. This is due to a difference in poultry management. Prior research conducted by Moore et al. (2000) utilized smaller birds (1.82 kg at market age) than the current study (2.72 kg at market age). Larger birds produce much more manure, hence more ammonia, which requires more acidity to keep it in the non-volatile ammonium form.

Table 1 – Average weekly ammonia concentrations (ppm) in poultry houses containing untreated and alum-treated litter (from Moore et al., 2008).

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Average
High rate dry alum	9.4	8.5	20.9	25.9	27.0	26.1	20.1	19.7
Low rate dry alum	18.4	22.9	32.2	32.4	33.5	34.2	24.3	28.3
Low rate liq. Alum	14.0	19.8	30.0	28.5	33.6	25.8	23.3	25.0
Control	38.6	38.0	41.0	36.5	38.8	32.3	25.0	35.7

Table 2 – Average weekly ammonia emissions (kg NH_3/wk-house) in poultry houses containing untreated and alum-treated litter (from Moore et al., 2008).

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Average
High rate dry alum	8.6	2.6	31.3	81.5	99.4	185.2	211.3	88.6
Low rate dry alum	15.7	19.0	43.0	91.7	91.8	170.4	259.5	98.7
Low rate liq. Alum	10.2	13.7	42.1	106.7	135.2	232.6	311.7	121.7
Control	45.0	45.9	58.8	115.9	134.7	227.7	314.3	134.6

Limitations:

When litter is treated with alum the litter pH decreases, which reduces ammonia volatilization. However, as broilers add more manure to the litter, the litter alkalinity uses up the acidity provided by the alum, causing the litter pH to increase with time. Hence, alum will loose it's effectiveness over time. Since alum begins working as soon as it's applied, birds should be placed 2-5 days after application. Dry alum results in dusty conditions during application; as such, dust masks and goggles should be worn by applicators. Alum has a low pH and can be corrosive to handle, hence gloves should be worn. The cost of alum is variable, dependent upon proximity of the production facility to the supplier

Cost:

As mentioned earlier, treating poultry litter with alum lowers ammonia levels in poultry rearing facilities and reduces pathogens in the litter and on birds. This results in a healthier environment for the bird, which results in better performance. It also reduces energy consumption, since less ventilation is required. The improvements in feed conversion, weight gains, mortality, condemnation, propane and electricity use, and nitrogen content in litter are shown in Table 3.

Table 3 – Summary of production parameters in alum-treated and untreated poultry houses for a flock of 20,000 broilers grown to 42 days of age. Taken from Moore et al. (1999).

	Alum-treated houses	Control houses
Propane use (L/flock)	3,020	3,357
Electricity use (kW/flock)	7,320	8,330
Weight gains (kg/bird)	1.73	1.66
Feed conversion (kg feed/kg bird)	1.98	2.04
Mortality (%)	3.90	4.20
Percentage of total bird weight rejected at processing (%)	1.50	2.00
Litter N content (%)	3.85	3.45

Each one of these parameters results in a monetary savings to either the grower or the integrator or both. The estimated savings associated with each parameter is shown in Table 4. The total savings to the integrator and the grower were estimated to be $632 and $308, respectively. The cost of energy, feed, poultry meat, and nitrogen have all increased since this work was completed. Hence, these benefits would be worth much more now. Likewise, the cost of alum has increased. When this work was done, alum cost approximately $200/ton. The cost of treating a typical broiler house in this study was $480, which included the spreading fee. Since the savings to the grower and integrator totaled $940, the benefit cost ratio was 1.96. Currently, alum cost about $350/ton.

Table 4 – Savings associated with alum to the integrator and grower per flock of broilers (20,000 four lb birds). Taken from Moore et al. (1999).

	Integrator	Grower
Lower propane use (assumed $0.32/L)	0	107
Lower electricity use (assumed $0.006/Kw)	0	6
Heavier birds ($0.11/kg)	0	150
Improved feed conversion ($0.001/point-lb bird)	480	?????[1]
Lower mortality ($0.41/bird for integrator, $0.35/bird for grower)	24	21
Higher percent total weight accepted during processing ($0.32/lb)	128	0
Higher litter nitrogen content (assumed $0.33/kg N)	0	24
Total Savings	$632	$308

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[1] The value of improved feed conversion to the grower varies from company to company.

Implementation:

The information in this report came from two different studies on the efficacy of alum to reduce ammonia emissions from commercial broiler farms (Moore et al., 1999, 2008).

Although alum can be applied to fresh bedding, it is typically applied to “used” bedding between each flock. If phosphorus control is also desired, then the alum should be tilled into the litter to allow optimum interaction between the aluminum in alum and phosphorus in the litter.

Alum application rates are dependent on the desired length of time that ammonia is to be controlled, with higher rates resulting in longer ammonia control. Recommended rates of alum vary from 0.045 to 0.09 kg/bird for an average sized

(1.82 kg) broiler (Moore et al., 2003, 2008). However, heavier birds result in higher manure production and more ammonia emissions. Therefore, when large birds are being grown, the final market weight of the bird should be considered when determining the alum application rate (0.025 to 0.05 kg alum/kg bird). Rates of 0.09 kg/bird have been shown to control ammonia for six weeks, while 0.045 kg/bird only controls ammonia for three weeks.

Reducing ammonia in poultry rearing facilities not only creates a safer environment for agricultural workers, it results in improved poultry performance. Improved weight gains, better feed conversion, lower mortality and condemnation rates have all been demonstrated in houses treated with alum. In addition, energy usage (propane and electricity) is reduced with alum because ventilation requirements are lower during winter months, as a result of lower ammonia levels. The fertilizer value of the manure is also improved, due to a higher nitrogen content, which results in higher crop yields. These agricultural benefits make this practice cost-effective. Environmental benefits of using alum include improved air quality (lower ammonia emissions), improved soil quality (lower levels of soluble phosphorus and reduced phosphorus leaching), and improved water quality (less runoff of phosphorus, estrogen and heavy metals. Hence, this is one of the few cost-effective best management practices that improves air, soil and water quality while enhancing poultry production and agronomic yields.

Technology Summary:

Alum additions to poultry litter reduce poultry house ammonia concentrations and emissions. Alum additions also result in decreased phosphorus runoff, improving water quality. There are three types of alum that can be used in poultry houses; dry, liquid and high acid liquid alum (this paper focuses on dry alum). Typically alum is not applied to fresh bedding material, but added to used bedding prior to each subsequent flock. Ammonia levels in poultry houses receiving alum have been shown to be reduced by over 75% for the first two weeks of the flock, 50% the third week, and 20-30% thereafter. However, the exact length of time that ammonia is controlled is dependent on the rate of alum application, with higher rates resulting in longer ammonia control. Recommended rates of alum vary from 0.045 to 0.09 kg/bird. However, these rates were based on broilers weighing 1.82 kg (4 lbs) at market age. Recently, more companies are growing larger broilers, which result in higher manure production and more ammonia emissions. Hence, for large birds the final market weight of the bird should be considered, with the corresponding range in alum application rates being 0.025 to 0.05 kg alum/kg bird. Alum application rates will be dependent on the desired length of time ammonia is controlled and whether or not controlling P runoff is desirable. Rates of 0.09 kg/bird have been shown to control ammonia for six weeks, while 0.045 kg/bird only controls ammonia for three weeks. Other benefits of alum include heavier birds, better feed conversion, lower condemnation rates and reduced propane use during cooler months as a result of lower ventilation needs. Crop yields are also higher with alum-treated litter because of higher nitrogen litter content. Phosphorus runoff and leaching are also reduced, improving water quality. The cost of alum is dependent upon both the chemical cost, the proximity of the production facility to the supplier, and the charge made by a third party to apply it (if applicable). In the economic evaluation made by Moore et al. in 1999, the cost of alum was \$0.26/kg alum applied (\$0.12/lb), which was equivalent to \$480 for a 1,459 m^2 house (16,000 ft^2) treated with 1,816 kg alum(4000 lb). Savings to the grower and integrator from lower propane and electricity use, heavier birds, improved feed conversion and lower condemnation totaled \$940, resulting in a benefit cost ratio of 1.96. As a result of these benefits, currently 700-800 million chickens are grown with alum each year.

Additional Resources:

Treating Poultry Litter with Alum http://www.uaex.edu/Other_Areas/publications/PDF/FSA-8003.pdf

Treating Poultry Litter with Aluminum Sulfate http://www.sera17.ext.vt.edu/Documents/BMP_poultry_litter.pdf

Treating Broiler Litter with Alum http://www.utextension.utk.edu/publications/infosheets/Pss318/PSS318.htm

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
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Using Liquid Aluminum Sulfate to Reduce Poultry Housing Ammonia Emissions

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Iowa State University[1], USDA Agricultural Research Service[2]

Species: Poultry (Broiler Chicken and Turkey)
Use Area: Animal Housing
Technology Category: Chemical Amendment
Air Mitigated Pollutants: Ammonia

Description:

Gaseous ammonia is released from litter during poultry broiler and turkey production, and various chemical amendments have been used to minimize ammonia emissions from poultry litter (Arogo et al., 2001). Work by Carlile (1984) indicates that in-house ammonia levels exceeding 25 ppm can result in decreased bird performance. Reduction of in-house ammonia emissions can improve bird performance and reduce emissions from poultry housing. During the first 14 days of the grow-out, while the birds are young, ammonia has the greatest negative effect on a bird's performance. Therefore, ammonia control during the first half of a grow-out provides the greatest benefits to bird performance during growth, while also decreasing the overall ammonia emissions from the production house.

In a study assessing the mitigation potential of multiple chemical amendments performed by Moore et al. (1999), it was concluded that application of dry/granular alum to chicken litter resulted in the best combination of environmental and economic benefits of the tested amendments. Additional research now shows that liquid alum can also be used to mitigate ammonia emissions from poultry broiler facilities. Use of liquid alum requires application of chemical to litter prior to bird placement, and it can be applied from a truck fitted with a tank and spray nozzles as shown in Figure 1.

In addition to reducing ammonia emissions from poultry facilities, other benefits to using liquid have been reported as follows (Moore et al., 2003):

- Safer environment for farm workers and birds due to reduced ammonia levels in the house,
- Improved bird health and food safety through reduced pathogen levels in the litter, and
- Less ventilation required during cooler temperatures resulting in reduced propane use for heating.

Mitigation Mechanism:

The litter in poultry production houses consists of manure and the bedding material. The rate of ammonia volatilization from litter is dependent on pH, moisture content, air velocity, manure nitrogen concentration, and temperature. The pH of the litter is an important factor in controlling ammonia volatilization because it determines the ratio of volatile ammonia to ammonium, the ionic and non-volatile forms of ammonical nitrogen. Application of alum reduces the litter pH and therefore suppresses ammonia emissions. The extent of pH reduction and the length of time the pH reduction remains effective is related to the rate of liquid alum applied. With increasing liquid alum application rate, the litter pH decreases and as pH decreases, ammonia suppression increases.

Additionally, effective suppression of in-house ammonia levels may reduce ventilation requirements. During the winter months when exchanged air must be heated upon entry into a poultry house, a reduction in ventilation also results in lower heating costs for the production facility. Combined, reductions of ammonia levels emitted from the litter and reductions in ventilation rate, reduces overall ammonia emissions from the production house.

Applicability:

Liquid alum application is effective at mitigating ammonia emissions in poultry housing systems that produce animals on litter, such as in turkey and broiler chicken production systems. As shown in Figure 2, using liquid alum, ammonia levels can be held below 25 ppm in the house for the first 3 to 3.5 weeks of production for an improved animal environment and a reduction in gaseous emissions. Liquid alum should be applied between grow-outs; it can be applied to either new bedding or de-caked litter. Additional benefits of liquid alum application include a potential reduction in pathogen levels and reduced use of propane for heating during cooler temperatures. The high acidity of liquid alum helps reduce pathogens in the litter providing a better environment for the birds. And, lower ammonia levels in the house can reduce the overall air exchange in the house. During cooler months, reducing the volume of air exchanged results in lower supplemental heating requirements.

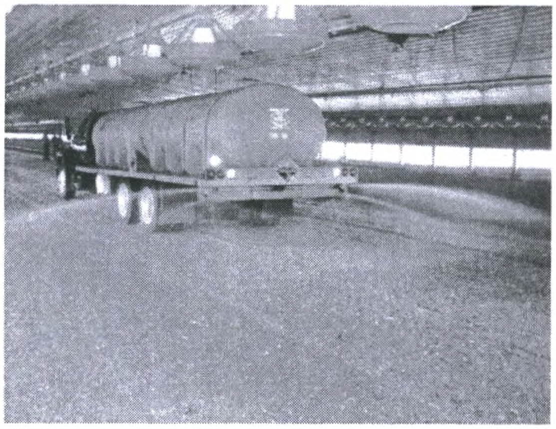

Figure 1. Liquid alum application.

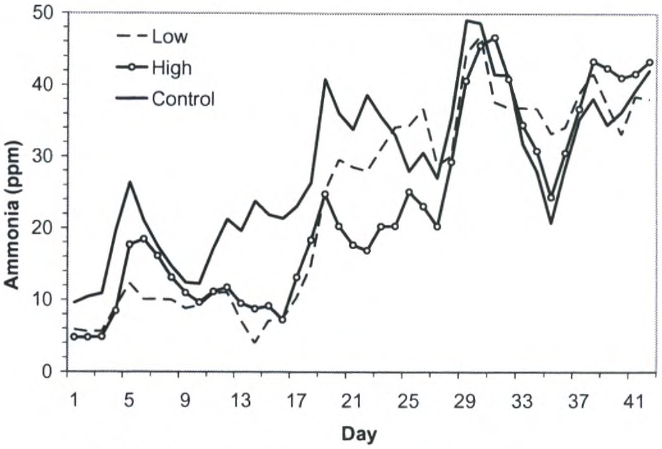

Figure 2. In-house ammonia concentrations based on liquid alum application rate.

Limitations:

Liquid alum is an acid; therefore, it is corrosive and can be hazardous to work with. Appropriate measures, as defined by the chemical supplier, should be used during handling of liquid alum. Like all acids, safe handling precautions should be used including gloves and eye protection. Generally, liquid alum will be applied by the supplier thus reducing any hazard to the producer during application.

Additionally, application of liquid alum only provides a temporary reduction in ammonia emissions from litter. Research results suggest that levels are equal to that of litter receiving no liquid alum three weeks into the bird grow-out. And, due to corrosiveness and bird disturbance it cannot be reapplied while animals are in the production area.

Cost:

The cost of using liquid alum is dependent upon the proximity of the production facility to a liquid alum distributor. Distributor cost is reflective of transport and chemical costs. For the costs discussed here, the production facility was 370 km (230 miles) from the distributer and the delivered liquid alum cost was 0.16 cents/L (0.60 cents/gal). The cost associated with liquid alum amendment is the cost of the material and transport and application fee. In this case, the application fee was $40/house. Cost savings from a reduction in propane use and reduction in the number of animal mortalities using liquid alum are expected to be similar to the savings achieved when using dry alum.

In the study discussed here, the cost per 1,824 m^2 (20,000 ft^2) production house was $262 for an application rate of 0.82 L/m^2 (0.02 gal/ft^2) and $504 for an application rate of 1.64 L/m^2 (0.04 gal/ft^2). In this case, the proximity of the production facility to the distributor was favorable, and the cost of applying liquid alum was less than the cost of applying the equivalent amount of dry alum. Table 1 shows a liquid and dry alum product cost comparison using dry alum rates equivalent to the liquid alum rates represented here. The liquid alum used in this study was a 48.5% alum Al Clear product produced by the General Chemical company.

Table 1. Liquid and dry alum product cost comparison.

Product	Application Amount	Cost per Unit Kg or L (cents)	Total Cost per house ($)
Liquid Alum (low)*	1514 L	0.16	242***
Liquid Alum (high)*	3028 L	0.16	484***
Dry Alum (low)**	907 Kg	0.33	299
Dry Alum (high)**	1814 Kg	0.33	599

* Liquid alum rates are 0.82 and 1.64 L/m^2 (0.02 and 0.04 gal/ft^2), considered low and high rates, respectively.

** Dry alum rates are 0.5 and 1 kg/m^2 (0.1 and 0.2 lb/ft^2), on an aluminum basis, considered low and high rates, respectively.

***For direct product cost comparison with dry alum, this cost does not include the $40 house application fee.

The broiler chicken production facility representative of these economics was stocked at 30,000 birds per house. For the low application rate, the cost of liquid alum amendment is $0.009/bird produced. And, for the high application rate, the cost of liquid alum amendment is $0.017/bird produced.

Implementation:

Information reported here concerning the use of liquid alum to reduce ammonia emissions is based on data from a study performed using four tunnel ventilated broiler production units measuring 152 m by 12 m (500 ft by 40 ft). The recommended application rates were tested during multiple 42-day flocks where birds were placed as day old hatchlings and caught at 2.25 kg (5 lb) slaughter weight.

Liquid alum can be applied to fresh bedding or aged litter. Liquid alum should be applied for each new flock after the litter has been prepared for bird placement into the production house (following either placement of new bedding, litter de-caking and a drying period, or placement of additional bedding on existing litter). The application rates discussed here were tested against a non-amended control house.

Selection of liquid alum rate is dependent upon the amount of ammonia control required for the facility. Suggested liquid alum application rates are 0.82 and 1.64 L/m^2 (0.02 and 0.04 gal/ft^2), considered low and high rates, respectively. On an aluminum basis, these rates are equivalent to 0.5 and 1 kg/m^2 (0.1 and 0.2 lb/ft^2) of dry aluminum sulfate, considered low and high rates, respectively. Generally, liquid alum will be applied by a commercial truck equipped with nozzles. This means that all instrumentation within the house (feeders, waterers, scales, etc) will need to be raised above the height of the truck during application.

A liquid alum application rate of 0.82 L/m^2 (0.02 gal/ft^2) will suppress ammonia concentrations below 25 ppm for the first 2.5 weeks of a flock grow out. Ammonia concentrations above 25 ppm decrease bird performance, especially in young birds. A liquid alum application rate of 1.64 L/m^2 (0.04 gal/ft^2) will suppress ammonia concentrations below 25 ppm for the first 3.5 weeks of a flock grow out. However, after 3.5 weeks ammonia concentrations will appear similar to those in non-amended production houses.

During the liquid alum study discussed here, mortalities were tracked during the study. An example of the mortalities numbers from one grow-out are as follows; the production house not amended with liquid alum (the control) had 1,100 mortalities while the production houses with low and high liquid alum application rates had 1,082 and 989 mortalities, respectively. An even higher liquid alum application rate of 2.46 L/m^2 was also tested and had even fewer mortalities (939); however, the ammonia concentrations in the house were not different then those achieved with an application rate of 1.64 L/m^2 (0.04 gal/ft^2). While the houses treated with liquid alum had lower mortalities than the control house in this study, there was no statistical difference in mortality numbers between the houses.

Technology Summary:

Liquid alum is a method to mitigate ammonia emissions from poultry broiler facilities. Use of liquid alum requires application of chemical to litter prior to bird placement, and it can be applied from a truck fitted with a tank and spray nozzles. Application of alum reduces the litter pH and therefore suppresses ammonia emissions. The extent of pH reduction and the length of time the pH reduction remains effective is related to the rate of liquid alum applied. Application of liquid alum only provides a temporary reduction in ammonia emissions from litter. Research results suggest that levels are equal to that of litter receiving no liquid alum 3.5 weeks into the bird grow-out. In the study discussed here, the cost per 1,824 m^2 (20,000 ft^2) production house was $262 for an application rate of 0.82 L/m^2 (0.02 gal/ft^2) and $504 for an application rate of 1.64 L/m^2 (0.04 gal/ft^2); this is equivalent to $0.009 and $0.017 per bird produced. In addition to reducing in house ammonia levels, there is some evidence that using liquid alum will also reduce mortalities through improved bird health and reduce propane use during cooler months because of reduced ventilation requirements.

Additional Resources:

Treating Poultry Litter with Alum http://www.uaex.edu/Other_Areas/publications/PDF/FSA-8003.pdf

Treating Poultry Litter with Aluminum Sulfate http://www.sera17.ext.vt.edu/Documents/BMP_poultry_litter.pdf

Treating Broiler Litter with Alum http://www.utextension.utk.edu/publications/infosheets/Pss318/PSS318.htm

Acknowledgments:

Project support was provided by Koch Foods, General Chemical, Inc., and The Tennessee Agricultural Experiment Station (via Regional Project S-1000).

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
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Litter Management Strategies in Relation to Ammonia Emissions from Floor-Raised Birds

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Species: Poultry (Broiler Chicken and Turkey)
Use Area: Animal Housing
Technology Category: Management and Chemical Amendment
Air Mitigated Pollutants: Ammonia

Description:

Poultry producers in the United States have attempted to maintain barn aerial ammonia (NH_3) levels below 25 ppm to improve air quality and, more recently, to decrease gas emissions to the atmosphere. Poultry are most susceptible to elevated ammonia level during 1 to 21 days after hatching, the *brooding period*. Ammonia emission to the atmosphere contributes to fine particulate matter formation, regional haze, nitrogen deposition in sensitive ecosystems, and acidification of soils. Regulatory scrutiny of ammonia emissions from animal agriculture is currently increasing.

Broiler chickens and turkeys are floor-raised on litter that starts as new bedding (sawdust, wood shavings, rice hulls, etc.) and becomes a mixture of decomposing manure and bedding as birds grow. Litter is the source of volatilizing ammonia in poultry production and its management is a key factor affecting emission rate and bird health. Various strategies are currently employed to manage litter to minimize bird exposure to high ammonia concentrations. Reducing litter moisture content and pH are the major means of reducing ammonia volatilization. Litter pH is reduced by applying acidifying compounds to litter prior to new flock placement.

New bedding may be placed in the barn every one to two years and then used repeatedly over many flocks, which is known as *built-up* litter. The accumulated built-up litter is eventually removed from the barn and fresh bedding is added. This reuse of litter is currently the most common American industry practice. A minority of USA broiler barns receive new bedding for each flock although this is common practice, particularly in the brood area, in other countries (Australia, Brazil and much of Europe). Turkey are raised in a two-step housing process with poults placed on new litter every flock in the brooding-house but the finishing-house typically utilizes built-up litter.

Use of new bedding every flock is intuitively a management choice for good air quality with reduced ammonia concentration within the house for bird and worker health while concurrently reducing ammonia emissions to the environment. Ammonia levels in the chick/poult environment are negligible for the first several days after placement.

New bedding for every flock has been *inhibited* for the following reasons:

- Cost of new bedding
- Real or perceived shortage of suitable bedding materials
- Limited litter-manure storage capacity, market for increased litter volume, or land for application
- Lack of tradition for this poultry management approach in the USA

New bedding for every flock has been *adopted* for the following reasons:

- Greatly improved brooding environment ammonia levels
- Lower ventilation rate, and fuel savings, early in flock
- Reduced disease challenge from previous flocks
- Nearly equivalent labor time for litter management between flocks for new or built-up litter

Acid-treated litter remains a popular ammonia control management option particularly for flocks started during cold weather. Acid treatment products useful in poultry housing include alum (aluminum sulfate), sulfuric acid, and sodium bisulfate; trade names, respectively, include Al+Clear, Poultry Guard, and Poultry Litter Treatment [PLT]. Litter treatments produce variable results, depending on material choice, product application rate and house management (ventilation, moisture control, etc.). Rather than being strictly used to improve air quality, litter treatments are often combined with reduced ventilation rate during the brooding period to save fuel.

Litter acid treatments have been *inhibited* due to:

- Inconsistent results in ammonia reduction to recommended levels
- Materials cost and labor for application

Litter acid treatments have been *adopted* for the following reasons:

- Simple, ease of use with relatively low cost
- Reduced ventilation rate possible to reduce supplemental heat needs
- Familiar management approach

Mitigation Mechanism:

For built-up litter, the current strategy is to reduce litter moisture and/or pH to reduce ammonia volatilization. Litter moisture is controlled year-round through reducing drinking water delivery system leaks with additional effort during cold weather to eliminate condensation drips from cold water pipes and walls and litter wetting from poor distribution of cold ventilation inlet air. Proper litter moisture is maintained by adequate ventilation air exchange based on humidity control that removes moisture-laden air, which impacts litter moisture levels. Beyond this, the most widely used method of suppressing ammonia volatilization from poultry litter is the application of acidic materials to reduce litter pH.

The production and volatilization of ammonia is inhibited by litter pH below 7 and can be substantial above pH 8. Keeping litter pH below 7 is the key to reducing ammonia volatilization. Uric acid is excreted in poultry manure and is the precursor to ammonia through a series of microbial and enzymatic processes. Uric acid breakdown is favored in alkaline conditions (above neutral pH 7). Acidic pH, below 7, also favors equilibrium of ammonium (NH_4^+), which does not volatilize, versus ammonia (NH_3). Acidic litter has unfavorable conditions for microbial and enzymatic reactions needed to convert uric acid in the manure to ammonia compounds; uricase, which degrades uric acid, reaches it peak at pH 9. However, control of litter pH over the life of the flock has proven to be a difficult task, in part because litter pH is not commonly measured, the effect of treatment is not long-lasting (typically only 10-14 days), and repeated treatments are usually impractical with birds in the building. The acidifying compound is applied to the litter, per manufacturer recommended rate, just prior to chick placement in the barn with an expectation of lowered ammonia volatilization during the critical brooding period (up to 21 d).

Ammonia also increases volatilization with increasing temperature, however, warm litter temperatures are required during the chick brooding period (28-34°C [85-92°F]) and then throughout the flock cycle (down to about 21°C [70°F]). Separately stored manure will be at a reduced outdoor temperature with lower ammonia volatilization potential and opportunity to apply other management tools that are impractical when birds are present.

New litter every flock obviously removes the ammonia source, the accumulated manure, from the bird environment to storage where it can be more aggressively managed for reduced ammonia emission.

Applicability:

Floor-raised birds starting on new litter each flock is common for turkey poults and for broiler chick management throughout most of the world. Antibiotic-free chicken production is more likely to utilize new litter each flock to decrease disease challenge. New litter is an option where suitable bedding material is available at a reasonable price. New litter results in nearly 0 ppm ammonia level in the bird environment for the first week of production. Ammonia concentration increase after that is dependent upon overall house management (litter moisture, ventilation rate, etc.). Emissions from new litter raised birds may be represented by equations found in Figure 1 (Wheeler et al., 2006).

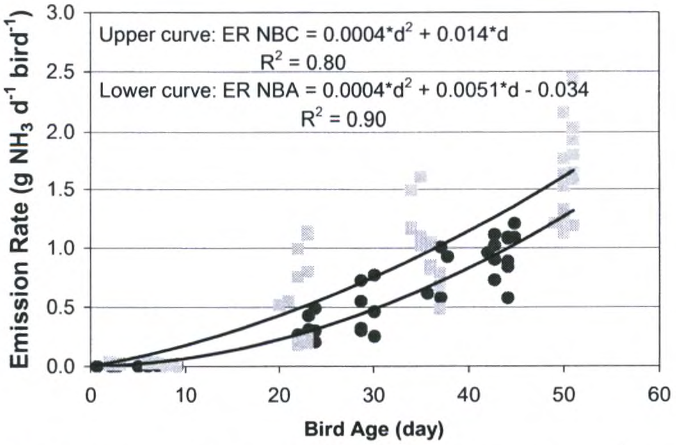

Figure 1. New bedding emission rate (ER) is expressed with second-order polynomials to characterize the near zero ER during the first week of the flock; NBC is *new bedding litter* flock after annual litter *cleanout*; NBA is *new bedding litter always* (every flock). Data are from 10 flocks over one year of data collection at commercial broiler houses: 2 NBA houses on one farm x five flocks each; 10 NBC houses on three farms x one flock each.

The practice of acidifying litter to reduce ammonia volatilization is widespread where built-up litter is used. The addition of granular or liquid acidifying compounds onto the built-up litter is relatively easy prior to bird placement in the house but may not be practical after birds are present. There is evidence that manufacturer's recommended product application rate is not reducing pH below 7 for favorable ammonia-ammonium balance in the field. This is further supported by higher application rates proving more effective in reducing aerial ammonia concentration. Most studies have focused on in-house aerial ammonia levels with more recent studies also incorporating emission rate.

Table 1. Summary of ammonia emission rate (ER) equations for the litter management strategies described and an estimate of daily per bird emission at various bird ages. Data are from 397 days of data collection from 12 houses on four commercial broiler farms in Kentucky and Pennsylvania.

Litter Code	ER Equation	R^2	ER (g NH_3 b^{-1} d^{-1})				
			day of age				
			1	7	20	42	60
NBA	= 0.0004*d2 + 0.0051*d - 0.034	0.90	0.00	0.02	0.23	0.89	1.71*
NBC	= 0.0004*d2 + 0.0140*d	0.80	0.01	0.12	0.44	1.29	2.28
TL	= 0.0295*d + 0.0121	0.66	0.04	0.22	0.60	1.25	1.78
BL	= 0.0311*d + 0.0824	0.60	0.11	0.30	0.70	1.39	1.95
AL	= 0.0308*d - 0.0321	0.64	0.00	0.18	0.58	1.26	1.82

NBA = new bedding always; NBC = new bedding after cleanout; TL = treated litter; BL = built-up litter; AL = all litter in this study. *extrapolated beyond 45 day data collection timeframe.

Table 2. Emission rate (ER) of ammonia from side-by-side comparison of four broiler houses on one farm where two had acid-treated built-up litter (TL) and two were built-up litter (BL). All four houses had an annual new litter cleanout (NLC). All houses on this farm are summarized as AL.

Litter Code	ER Equation	R^2	ER (g NH_3 b^{-1} d^{-1})				
			day of age				
			1	7	20	42	60
NBC	= 0.0006*d2 - 0.0038*d	0.93	0.00	0.00	0.16	0.90	1.93
TL	= 0.0266*d + 0.156	0.49	0.18	0.34	0.69	1.27	1.75
BL	= 0.0282*d + 0.080	0.45	0.11	0.28	0.64	1.26	1.77
AL	= 0.0280*d + 0.031	0.50	0.06	0.23	0.59	1.21	1.71

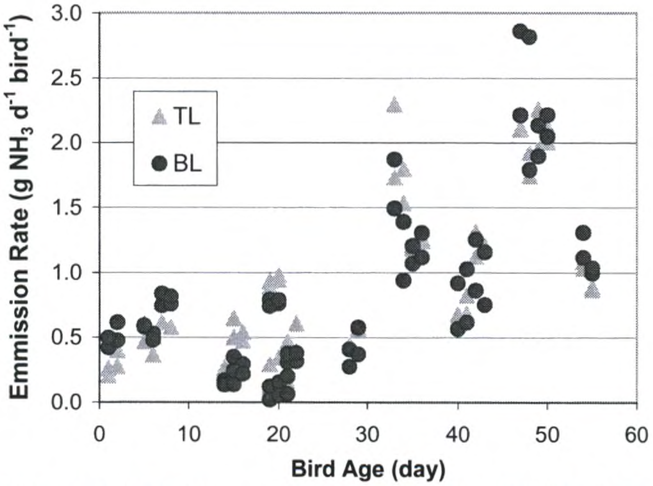

Figure 2. Field study of sodium bisulfate treated (TL) litter versus untreated built-up (BL) litter in four commercial broiler houses (2 TL; 2 BL) on same farm for direct comparison of ammonia emission rates (ER); additional data in Table 2. Minimum cold-weather ventilation was provided by timer fans on a 10 minute interval at 3 minutes run time in the TL houses whereas the BL houses utilized 5 minutes run time, 67% more, in an attempt to control ammonia levels. Note that the daily ammonia ER is higher for the BL houses during the first 10 days then this pattern reverses after about two weeks when the TL house emissions are greater than the BL houses for a given day. This indicates a release of the ammonia held in the treated litter as the acidifying power of the treatment product is depleted. The litter pH was above 8 for all four houses on the day of chick placement.

Limitations:

Acidifying compounds can reduce aerial ammonia concentration within a poultry house. Heavier than manufacturer-recommended acid application rates appear to result in improved air quality but with increased cost. When acid treatment is used in conjunction with reduced ventilation rate, in an attempt to lower fuel costs, the ammonia reduction benefit is minimized. Data from field trials indicate that acid treated litter is used as often for fuel reduction as it is an attempt to improve the bird environment ammonia level. A side-by-side study of four broiler houses, two with sodium bisulfate (PLT) acid treated litter and two houses with no acid treatment, showed that ammonium held in the acidified litter during the first two weeks was subsequently released and resulted in essentially the same ammonia emissions from all four houses over the course of the flock (figure 2, table 2). Other research has failed to demonstrate a difference in ammonia emissions from litter treated with sodium bisulfate and untreated litter (Moore et al., 1996).

Cost:

It takes a similar amount of time to prepare a house with new bedding or built-up litter for the next flock. This relates to the one-time effort for full litter removal versus more careful and repeated management needed for built-up litter preparations. Management priorities vary greatly throughout the country, partially dependent on climate, and we try to capture some of that variation here.

A full cleanout of litter takes about 16-man-hours, including stockpiling litter into a covered storage. It takes an additional 2 man-hours using a bedding spreader to apply new bedding. Cost of new bedding is quite variable from about $600 [wood shavings in NE] to $1000 [rice hull + wood shaving mix in SE]. Accounting for differences in house size between regions and bird placement numbers, new bedding cost ranges from $0.018 to $0.045 per bird. Ventilation rate is substantially reduced during the first few days after bird placement on fresh bedding to levels needed for moisture control. Ventilation rate to keep aerial ammonia within the 25 ppm guideline on built-up litter can be 10 times higher than for moisture control alone. Energy savings can be substantial on new bedding through reduced supplemental fuel use during the warmest period of brooding. A slightly increased bird placement density on new bedding may be acceptable due to the reduced environment challenges versus a built-up litter house.

About 16 man-hours are needed to properly prepare a built-up litter house for the next flock. During built-up litter decaking (removing caked litter under the feed and water lines), about one-fourth of the litter is removed to the manure storage; 15 US-ton litter/house/flock (US-ton = 2000 lb or 909 kg). The remaining litter is bladed to evenly distribute and then harrowed (roto-tilled; housekeeping machine, etc.) everyday for 2 or 4 days to help dry the litter.

If an acid litter treatment is applied, this takes about 1 man-hour per house-section using a small spreader pulled behind a lawn tractor. Treatment is applied 2 to 24 hours before bird placement, in stages as different sections of the house are prepared to receive birds. Broiler production often divides the house into subsections to reduce the heated area during brooding higher temperatures. The first one-half of the building is used for brooding, then additional area is opened. A cost estimate is available from the study that monitored treated litter houses (Figures 1 and 2). Cost of sodium bisulfate (PLT) is about $13 per 22.7 kg (50-lb) bag when purchased by the US-ton (one pallet), plus delivery (2008 price). At an application rate of 0.24 kg/m^2 (50-lbs per 1000 ft^2) 25 bags are needed ($335) per 14.6 m x 152.4m (50 ft x 500 ft) house placing 32,500 birds for $0.01 per bird. In moderate climate regions, only the brooding area is treated at half this cost.

The built-up and caked litter removed to storage may be stockpiled for crop use or sold to specialized outlets such as composting or mushroom substrate operations at $4.5/US-ton. Alum can stabilize ammonium into ammonium sulfate to further reduce volatilization. Alum-treated litter reduces losses of soluble and total phosphorous (P) in runoff from land-applied litter and benefits P-based land application guidelines.

Implementation:

Acid-litter treatments are usually applied according to product manufacturer's directions. Consider that several studies have found increased effectiveness under commercial conditions when the product is applied at a higher rate, particularly when built-up litter has accumulated from several flocks (perhaps 4 or more). One way to gauge effectiveness of an acidifying treatment is to check litter pH to be sure it is reduced below 7 after acid treatment. For example, Wheeler et al. 2008 report that after five flock growouts the litter pH at chick placement was about 8.05 for two PLT-treated houses (at recommended rate of 0.24 kg/m^2), which was lower than two untreated houses (pH 8.3) on the same farm. After 7 days pH was 8.2 in the treated houses with all four houses having essentially the same pH at flock end. More acidifying material was needed on the accumulated litter material to reduce the pH below 7 for this acid treatment to be effective.

Technology Summary:

Managing floor-raised poultry offers options for providing a suitable environment for the bird productivity and an opportunity to reduce environmental pollution. Reduction of aerial ammonia concentration within the poultry house will benefit bird health for improved productivity and reduce emissions from the building. Three management options were discussed here: 1. new bedding every flock; 2. built-up litter; 3. built-up litter with acidifying product.

Indoor ammonia level and emissions are most improved with use of new litter every flock. Adoption of this practice is very limited in the USA. Built-up litter is most common in the USA. Acidifying treatments are applied to built-up litter in an attempt to reduce litter pH below 7 to overcome the substantial ammonia volatilization.

Acid treatments have offered variable results under field conditions in reducing in-house aerial ammonia levels and associated emissions. Variable results are, in part, due to a primary management objective to reduce ventilation rates to lower supplemental heat expenditures after application of acid treatment. Reduced ventilation fresh air exchange results in increased house humidity and ammonia concentration within the building. Attention to litter pH and aerial humidity after application of acid-treatment should improve results for more consistent aerial environment improvement.

Cost of implementing new litter every flock equivalent to the labor cost for built-up litter. New bedding material cost is higher than acid-treatment cost at additive manufacturer rates. New litter benefit reported here does not account for reduced energy use during brooding and increased bird placement numbers with the improved environment

Additional Resources:

Blake, J. P. and J. B. Hess. 2001. Auburn University, AL. Available www at:

- Aluminum Sulfate (Alum) as a Litter Treatment, ANR-1202. www.aces.edu/pubs/docs/A/ANR-1202/
- Litter Treatments for Poultry, ANR-1199. www.aces.edu/pubs/docs/A/ANR-1199/
- Poultry Guard™ as a Litter Amendment, ANR-1209. www.aces.edu/pubs/docs/A/ANR-1209/
- Sodium Bisulfate (PLT) as a Litter Treatment, ANR-1208. www.aces.edu/pubs/docs/A/ANR-1208/

Poultry Litter Amendments. 2006. S. Shah, P. Westerman and J. Parsons. North Carolina Cooperative Extension Service. www.bae.ncsu.edu/programs/extension/publicat/wqwm/poultry/factsheet_agw657long.pdf

Wheeler, E. F., K.D. Casey, R.S. Gates, and H. Xin. 2008. Ammonia emissions from USA broiler barns managed with new, built-up, or acid-treated litter. *Proceedings of the Eighth International Livestock Environment Symposium*. Iguassu Falls City, Brazil. ASABE. St. Joseph, MI. 10 pp.

Acknowledgments:

Financial support was provided by the USDA-IFAFS program and we sincerely thank the participating integrators and farmers for their support and cooperation throughout this study.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
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Animal Housing-Diet Modification

Methane Emissions from Dairy Cattle

L. Chase
Cornell University

Species:	Dairy
Use Area:	Animal Housing
Technology Category:	Diet Modification
Air Mitigated Pollutants:	Methane

Description:

Global warming and air quality concerns have focused attention on animal agriculture as one source contributing to these problems. Methane is the greenhouse gas that has received the most attention relative to emissions from animals. In 2005, the total greenhouse gas emissions in the U.S. were 7,260 Tg CO_2 equivalents (EPA, 2007). This value has increased by 16.3% from 1990 to 2005. Methane emissions were 539 Tg on a CO_2 equivalents basis. This value has decreased 11.4% since 1990. Methane emissions from enteric fermentation were 112.1 Tg on a CO_2 equivalent basis in 2005 versus 115.7 in 1990. This is a decrease of 3.1%. Thus, there has already been some decrease in both total and enteric fermentation methane emissions in the U.S. since 1990.

Enteric methane emissions are produced in ruminant animals as a result of microbial degradation of carbohydrates in the rumen. Enteric methane accounted for about 21% of the total U.S. CH_4 emissions in 2005. Methane emissions from dairy cattle represented about 25% of total enteric CH_4 emissions while beef cattle accounted for 71%. Methane emissions from all cattle in the U.S. account for about 11% of the world methane emissions from cattle (Westberg et.al. 2001).

Table 1 contains data on methane emissions from dairy cattle in the U.S. for 1944 and 2007. The highest number of dairy cattle in the U.S. was in 1944. Methane production was calculated using the Cornell Net Carbohydrate and Protein System (CNCPS, 2007) model. It is important to note that total U.S. milk production increased by 159% from 1944 to 2007 even though the number of dairy cows decreased by 64.5% during this time period. This was accomplished by a 443% increase in milk production per cow during this time. Methane emissions per pound of milk produced decreased 60% during this same time period. Thus, the dairy industry has already made significant reductions in methane emissions since 1944. This decrease in total methane emissions from dairy cattle is the result of many factors including animal genetics, feed quality, ration formulation, feeding management and changes in herd management.

Table 1. U.S. Dairy Cow Statistics and Methane Emissions

Item	1944	2007	2007, % of 1944
Cows, millions	25.6	9.1	35.5
Milk, lbs/cow/year	4,572	20,267	443
Total U.S. milk production, million lbs.	117,023	185,602	159
Milk, lbs/cow/day	15	66	440
Methane, Mcal/day/cow	3.05	5.3	174
Methane, l/cow/day	332	580	175
Total Methane, l/day, millions	8,499	5,278	62
Methane, l/lb of milk	22	8.8	40

Mitigation Mechanism:

There are a large number of potential approaches that can be used to decrease total methane emissions from dairy cattle or to lower the methane produced per unit of milk produced. The basic objective is to improve the efficiency of both animal productivity and ruminal fermentation. A number of papers have addressed methane mitigation options for ruminant animals (Benchaar et.al., 2001; Boadi et.al., 2004; Chase, 2006 and Johnson et. al. 1996). The primary approaches that can be used include:

1. Continue to improve animal productivity – The information in Table 2 contains the relationship between daily milk production and methane emissions in dairy cattle fed the same ration. Note that as milk production increases the methane produced per cow per day increases. This is logical since the animal is consuming and processing larger

quantities of feed as milk production increases. However, the quantity of methane produced per unit of milk produced deceases as milk production increases. The net effect is that fewer animals would be needed to produce a specific quantity of milk resulting in less total methane being produced. Factors such as genetics, feed quality, ration formulation and daily nutrition management can all assist in increasing animal productivity. The use of rBST has been calculated to lower methane emissions in dairy cattle by up to 9% (Johnson et. al., 1996).

Table 2. Milk Production and Methane Emissions in Dairy Cattle

Milk, lbs/day	Dry matter intake, lbs/day	Methane, Mcal/day	Methane, l/day	Mcal of Methane/lb. of milk	Liters of Methane/lb. of milk
44	37	4.75	518	0.11	11.8
66	43	5.31	580	0.08	8.8
88	52	5.97	652	0.068	7.4
110	62	6.64	725	0.06	6.6
132	73	7.26	793	0.055	6.0

2. Feed high quality forages – Higher quality forages help to decrease methane emissions due their higher efficiency of use in the animal. A trial was conducted with lactating beef cows to evaluate methane production on two types of pasture (McCaughey et. al., 1999). An alfalfa-grass pasture (13% CP, 53% NDF) and a grass pasture (9% CP, 73% NDF) were used. Methane production was about 9% higher for cows on the grass pasture which is a lower quality forage.

3. Feed high grain or soluble carbohydrate rations – Feeding grain or soluble carbohydrates tends to increase ruminal propionate while lowering rumen acetate levels from the microbial fermentation. Previous work has indicated that methane emissions are increased as rumen acetate levels increase. Using a modeling approach, it was reported that replacing beet pulp with barley decreased methane emissions by 22% (Benchaar et. al., 2001). Using this same approach, a 17.5% reduction in methane emissions was reported when corn grain replaced barley in the ration. This is the reason that finishing beef steers in feedlot situations have low methane emissions compared with dairy cattle. An in vitro study also indicated that methane production decreased as rumen pH decreased (Russell, 1998). However, there are a number of rumen and animal health concerns that limit the quantity of grain that can be fed to dairy cattle. This limits the potential decreases in methane emissions that can be attained in dairy cattle by feeding higher grain diets.

4. Processing of forages – Lower methane losses per unit of feed intake have been reported when smaller particle size forages are fed (Johnson et. al., 1996). Forage particle size reduction has practical limitations for dairy cattle since there is a need to maintain chewing and rumination activity and rumen health. Most forages fed to dairy cattle in the U.S. are fed in the form of silage. The particle size of these forages is reduced during harvest but there is little opportunity for further decreases in forage particle size on most dairy farms.

5. Dietary fat sources – The addition of medium chain length fatty acids has been reported to lower methane production (Dohme et. al., 2000). Methane production has also been decreased by adding fish oil to rations (Fievez et. al., 2003). These fats were added as free oils. A trial with lactating dairy cows used whole cottonseed or canola seeds as fat sources to increase total ration fat levels from 2.3 to 5.6% (Johnson et. al., 2002). In this trial, the added fats did not reduce methane emission rates. This may be related to the fact that the fats in these products were part of a feed and may have had a slower release rate in the rumen and had less impact on ruminal fermentation. A review paper concluded that adding unsaturated fats may help to decrease methane production but may also have negative effects on feed intake or animal performance (Giber-Reverdin et. al., 2003).

6. Additives to alter rumen fermentation – A logical approach would be to add compounds to the ration that could alter rumen fermentation and decrease methane production. A large number of compounds have been screened for methane emissions using in vitro techniques. Many of these look promising but have not been used in animal trials. Methane production was decreased by 49 to 75% in growing lambs when an encapsulated fumaric acid product was used (Wallace et. al., 2006). The addition of sarsaponin to an in vitro rumen system decreased methane production up to 60% (Lila et al., 2003). Methane production has been decreased by up to 42% in an in vitro continuous culture system when an extract of *Yucca schidigera* or *Quillaja saponaria* was added (Pen et. al., 2006). The ionophore, monensin, has decreased methane production in ruminant rations (Guan et. al., 2006: McGinn et. al., 2004 and Tedeschi et.al, 2003). The proposed mechanism is a shift in the rumen microbial population that results in a higher propionic to acetic acid ratio. A recent paper examined the effect of including monensin in dairy rations over a 6-month period of time (Odongo et. al., 2007). Methane production was decreased by 7-9% when monensin was added. Dry matter intake and milk production were not affected when monensin was added but decreases in both milk fat % and

milk protein % were reported. The addition of monensin to dairy rations in the U.S. has been approved by FDA (Food and Drug Administration). The approved use level is between 11 to 22 g/ton of total ration dry matter.

7. Additional Approaches – A number of possible ways to reduce methane emissions have been tried in laboratory environments. These include immunization, vaccines, use of probiotics, adding essential oils and protozoal defaunation. All of these have some potential to decrease methane production in short-term in vitro trials. Long term animal trials are needed to determine if they have potential for practical use on dairy farms.

Applicability:

Reducing methane emissions on dairy farms is a practical and realistic goal. However, there must be some economic return to dairy producers if we expect them to adopt practices to decrease methane production. The practices used must also be practical and fit within the dairy herd management system. Practices that improve animal production and efficiency usually provide a positive economic return to the dairy producer. The practices listed above such as using higher quality forages and using various carbohydrate energy sources in the ration can be done on most dairy farms. Forage quality and ration formulation practices continue to improve on dairy farms and have both economic and environmental benefits to the producer. Feed efficiency has been shown to improve when monensin is fed to dairy cattle. This increases the quantity of milk produced per unit of feed consumed and improves the income over feed cost for the dairy producer.

Limitations:

There is no direct economic incentive for a dairy producer to develop a program to lower methane emissions. The incentive is rather an improvement in efficiency of feed use or an increase in farm profitability by fine tuning the forage and feed program on the farm. A large number of the possible approaches outlined above have only been tried experimentally and need additional animal research to verify or quantify their potential to alter methane emissions. There is also a question of balance. We could design rations for dairy cows to dramatically lower methane emissions. However, these rations may not be practical since they could lower animal productivity or impair animal health.

Cost:

It is very difficult to put cost or benefit values on the above practices as they will vary widely between farms. Cost and return analysis should be done on animal efficiency or productivity terms. In most cases, a practice that improves animal efficiency or productivity will also decrease methane emissions. One author has suggested that a 5:1 return can be attained by using monensin in dairy cattle rations (Hutjens, 2007).

Implementation:

The practices described above offer opportunities to dairy producers to alter nutritional practices to decrease methane emissions from dairy cattle. The type and extent of practices adopted will be farm specific and will need to be reviewed and discussed by the dairy producer and his outside consultants.

Technology Summary:

The U.S. dairy industry was responsible for about 21% of the total enteric methane emissions in 2005. The total methane emissions from dairy cattle have already decreased by 38% compared to 1944 while milk production per cow has increased by 443% during this same time. The liters of methane produced per pound of milk have gone from 22 in 1944 to 8.8 in 2005. There are still opportunities for the dairy industry to further decrease methane emissions. Since there is no direct benefit to a dairy producer to lower methane emissions, the primary changes will be to improve animal efficiency and productivity. By doing this, the methane produced per unit of product will be reduced. The primary areas to concentrate on to lower methane emissions are improving forage quality, better balancing rations to improve the efficiency of rumen fermentation and nutritional management practices to increase feed efficiency. A number of feed additives look promising for reducing methane emissions based on laboratory and in vitro results. However, most of these have not been tested in long-term experiments with dairy cattle. Until this is done, the potential reduction in methane emissions and the cost to benefit ratio cannot be determined. Monensin is one additive that has been shown to lower methane emissions and is approved for use in dairy cattle rations by FDA. One estimate is that the benefit to cost ratio for this product is 5:1.

Additional Resources:

EPA website: www.epa.gov/climatechange

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
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Environmental Responses to Dietary Monensin in Lactating Dairy Cows

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Species: Dairy
Use Area: Animal Housing
Technology Category: Diet Modification
Air Mitigated Pollutants: Methane, Nitrous Oxide, Carbon Dioxide, Methanol, Ethanol

Description:

Paramount amongst the problems currently facing the dairy industry is the impact the dairy industry has on the environment. A main environmental concern associated with the dairy industry is the emission of volatile organic compounds (VOC) and greenhouse gases (GHG). Volatile organic compounds interact with oxides of nitrogen in the presence of sunlight to form ozone (O_3). The major VOCs produced on dairies are methanol (MeOH) and ethanol (EtOH) (Shaw et al., 2007; Sun et al., 2008). Both of these alcohols are produced in the rumen and in the fresh waste primarily by gram-positive bacteria including *Streptococcus bovis* and *Ruminococcus albus* (Shaw et al., 2007). In 2004, California dairy cows and their waste were estimated by air quality agencies to contribute similar amounts of smog-forming VOCs as light/medium duty trucks or light passenger vehicles within the state (SJVAPCD, 2006).

Greenhouse gas emissions associated with dairies are also a significant challenge. The primary GHGs are methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). Livestock is considered a significant source of global CH_4 and N_2O emissions from enteric fermentation and their manure (IPCC, 2001). Contributions of CH_4 and CO_2 from lactating dairy cows were determined to be primarily derived from enteric fermentation and respiration (Jungbluth et al., 2001), and to a lesser extent from stored manure (Shaw et al., 2007). Livestock respiration contributes significant amounts of CO_2, approximately half of total CO_2 emissions from both humans and animals worldwide. Under the Kyoto Protocol, livestock contributions of CO_2 are not considered a net source because the plant matter being consumed previously sequestered atmospheric CO_2 (FAO, 2006).

Feed additives have been thought to improve cattle health and productivity, and have been used for these reasons for decades. One such additive, the ionophore monensin (trade name Rumensin®), has been shown in most studies to improve feed efficiency, improve rate of weight gain, and most recently, improved milk production efficiency (milk output per feed input), but with much inconsistency. These improved efficiencies result from changes in rumen bacterial populations and the sparing of metabolites used for production. Any improvements in production efficiencies serve to decrease emissions from cattle per unit produced (milk, rate of weight gain) relative to feed consumed.

Mitigation Mechanism:

Feeding the ionophore monensin to dairy cattle has the potential to alter CH_4 production in the rumen because it selectively reduces the levels of gram-positive bacteria. This is achieved because monensin inserts into the bacterial cell membrane of gram-positive bacteria and functions as an antiporter, translocating extracellular sodium (Na^+) or hydrogen (H^+) for intracellular potassium ions (K^+) (Russell and Houlihan, 2003). Destroying chemi-osmotic gradients across the bacterial membrane result in the inability of the bacterium to synthesize adenosine tri-phosphate (ATP), causing eventual cell death (Tedeschi et al., 2003). Because gram-positive organisms are more likely to produce H_2 and acetate as their fermentation end-products than gram-negative bacteria, cows fed monensin should produce less H_2 and acetate during enteric fermentation. Although monensin has little or no direct effect on methanogenic archaea, methanogenesis should be reduced due to the lower quantities of methanogenic substrates (i.e. H_2 and acetate) (Russell and Houlihan, 2003). The effect of monensin on N_2O and VOC emissions has not been previously reported.

Applicability:

Monensin is currently approved by the FDA to prevent and control coccidiosis, improve rate of weight gain, improve feed efficiency, and increase milk production efficiency in cattle. It can be utilized in beef, dairy, and calf operations. Increasing the efficiencies of the animal, both in health and productivity, serves as the best application for this feed additive. Potential reductions in VOC and GHG emissions should be considered secondary benefits.

Monensin has been reported to affect animal performance. Increased milk production was found by Sauer et al. (1998) and Gallardo et al. (2005) but other workers found no effect of monensin on milk production (van der Merwe et al., 2001, Erasmus et al., 2005, Benchaar et al., 2006, Odongo et al., 2007). Thus additional studies are needed to determine the effect of monensin on milk production. Similarly the effect of monensin on dry matter intake (DMI) has varied across studies. In several recent studies DMI did not differ when cows were supplemented with monensin compared with unsupplemented control groups (Erasmus et al., 2005, Gallardo et al., 2005, Benchaar et al., 2006). However, a review of 228 trials including 11,274 cattle (Goodrich et al., 1984), DMI decreased by 6.4 ± 5% when monensin was added to the diet (average 246 mg day^{-1}) indicating considerable variability in response to monensin, again suggesting that additional studies are needed.

The effect of monensin on GHG emissions, specifically CH_4, has been studied with varied results. Odongo (2007) reported a 7% reduction for CH_4 emissions over a six-month period when cows were fed monensin ranging from 307.3 to 708.1 mg day^{-1}; however, the difference in CH_4 emissions was not significant until the fourth month of their study. Thus a decrease in CH_4 emissions in response to dietary monensin might occur only long term. Short-lived (3-6 weeks) reductions of CH_4 emissions in beef steers were reported in the literature, but emissions eventually returned to pre-ionophore feeding levels (Guan et al., 2006). Short-lived CH_4 decreases in steers with emissions returning to control levels after 9-12 days were also reported (Carmean and Johnson, 1990, Rumpler et al., 1986).

Previous studies reported varied results for CH_4 reductions when cows were fed high dry matter diets, similar to those in our study (see below), and high moisture diets that primarily consisted of corn silage. It is not clear if the type of diet is the chief factor in determining the effects of monensin on GHG reductions.

In our study, monensin did not affect emissions of the GHGs (CH_4, N_2O, and CO_2), as well as smog-forming VOCs (MeOH and EtOH). In the recently conducted study in our lab, monensin fed at 600 mg $head^{-1}$ day^{-1} with an alfalfa hay-based total mixed ration did neither effectively reduce GHG and VOC emissions, nor impact animal performance or the microbial population structure of animal feces.

It is evident, due to such varied responses reported in the literature, that more research in this area is needed to determine the potential of monensin as a mitigation strategy.

Limitations:

Since ionophores are classified as drugs, the primary limitations associated with ionophores are the minimum and maximum feeding levels and intended uses as defined by the FDA. Feeding levels are specific to species and the type of operation (dairy, beef, calf), as well as the specific intended use (improved milk production efficiency, improved rate of weight gain, etc.). Current approved minimum and maximum feeding levels for dairy cows for increased milk production efficiency are 185 to 660 mg $head^{-1}$ day^{-1}. Secondary limitations include, but not limited to, cost to profit ratios which are determined by quality and cost of feed, and by current milk prices received by the producer per one hundred pounds of milk (cwt).

Directly measuring the impact of ionophores on air emissions can prove difficult, if not impossible for many producers. Therefore measurements have to be based on improvements of efficiencies of unit output per unit input. Potential improvements in efficiencies in response to the use of ionophores can help to amplify this reduction of emissions per unit of output.

Cost:

Feed costs can represent approximately 50-55% of total operation costs on a dairy. This trend continues to increase resulting in decreased profit margins. In the western United States, there is a trend toward less dependence on concentrate feedstuffs because of price, while dairy producers are attempting to maximize their use of farm owned feeds (silages and hay). As the percent of roughages in the ration increase, the quality of the forage should be considered before the potential use of feed additives that claim improve feed efficiencies.

Monensin is most commonly delivered to the animal in a mineral or grain premix. Depending on the type of premix, inclusion level of monensin, and cost of transportation, costs can vary widely. Depending on the method of delivery to the animal, the cost of the raw drug form of monensin (Rumensin® R80, 80 g lb^{-1}) can range from approximately \$0.0145 to \$0.072 cow^{-1} day^{-1}, delivering 185 to 660 mg $head^{-1}$ day^{-1}, respectively.

Implementation:

Monensin has been widely used in beef cattle operations for the past 30 years, as well as in US dairy operations since its approval in 2004 for use in lactating cows. The use of monensin is strictly determined by the definitions set by the FDA. Additionally, mixing of the raw drug form of monensin into feed is prohibited unless a license has been granted to the mixing facility by either state or federal government.

Technology Summary:

Feeding ionphores is believed to be a method to improve feed efficiency. Additionally, some studies have shown mitigation effectiveness for GHG emissions. Improvements in feed efficiencies for rate of weight gain and milk production equate to reductions of emissions per production unit. Increasing the efficiency of the animal will reduce the amount of emissions per unit of input. The use of ionophores has been shown to improve efficiency in the animal, although with inconsistent results. Many variables can impact the effect of ionophores including the type of diet and stage of production. Our study conducted in 2007, did not prove monensin to reduce emissions of the GHGs methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), as well as smog-forming VOCs methanol (MeOH) and ethanol (EtOH) when fed at 600 mg head^{-1} day^{-1} with an alfalfa hay-based total mixed ration. Additional work is needed to evaluate the impact of monensin on feed efficiency, dry matter intake, milk production, and emissions of both GHG and VOC in lactating cows using different diets, particle size of feed, and quality of the forage.

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As published in the proceedings of:
Mitigating Air Emissions from Animal Feeding Operations Conference
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
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U.S. Pork Center of Excellence

Diet Modification to Reduce Odors, Gas Emissions and Nutrient Excretions from Swine Operations

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Purdue University

Species:	Swine
Use Area:	Animal Housing
Technology Category:	Diet Modification
Air Mitigated Pollutants:	Ammonia, Hydrogen Sulfide, Volatile Fatty Acids, Volatile Organic Compounds, and Odor

Description:

Compatibility of pork production with neighbors in rural America is a major concern. When a pork operation moves into a rural community or expands an existing operation, the public often raise concerns about the potential impacts of the operation on water, air quality and health. Odor and gas emissions from pork operations primarily come from the anaerobic degradation of manure. Manure generated at pig facilities consists primarily of feces, urine, and some spilled water and feed. Nutrients excreted by the pig are from undigested feed ingredients and losses from normal metabolism. Since the pig is the initial point source of nutrients excreted and resultant gas and odor emissions, diet modification has the potential to reduce nutrients excreted and thereby reduce gas and odor emissions.

Pig diets are often formulated with a safety factor to assure that all pigs receive adequate nutrients to meet growth requirements and maximize gain. In addition, pig diets are often formulated on a least-cost basis using lower cost ingredients (by-product ingredients for example) which may result in feeding nutrients greater than the pig's requirements. The principle of using diet modification techniques is to carefully match available nutrients via feed ingredient selection to the specific nutrient requirements of the pig and thereby reduce excess nutrients in the diet. If lower levels of nutrients are excreted, then the precursors for odor and gas production are also reduced. In this research, low nutrient excretion (LNE) diets were formulated and fed to pigs in group feeding trials to determine the impacts on nutrient excretion, and gas and odor emissions.

Mitigation Mechanism:

Numerous compounds have been identified from anaerobic degradation of animal manures, and can be generally grouped as sulfurous compounds, indoles and phenols, volatile fatty acids (VFA), and ammonia (NH_3) and volatile amines (Lei, et al 2005). Many of these volatile compounds come from the degradation of amino acids and proteins. For example, indoles and phenols are derived primarily from the degradation of tyrosine, phenylalanine and tryptophan. Volatile sulfur containing compounds come from the amino acids methionine and cysteine plus mineral sulfates and other sulfides in the diet. Many of the VFA and methane are produced from the degradation of proteins and from the degradation of a multitude of fermentable carbohydrates in the feces by indigenous bacteria in the gastrointestinal tract. Since there is considerable variation in the chemical composition of feed ingredients and the availability of nutrients from those ingredients, the impact of diet composition can have a substantial impact on nutrient excretion, gas emissions and odor generation.

In a typical corn-soybean meal based diet, the ratio of amino acids provided in the diet does not match the ratio required by the pig for maintenance and growth (Sutton, et al 1999). Therefore, when the diets are formulated to meet the most limiting amino acid, lysine, there are excesses of other amino acids which the pig excretes. If the amount of soybean meal (primary protein source) concentration in the diet is reduced by using synthetic amino acids, there is significantly less nitrogen (N) excreted by the pig. This will reduce NH_3 emissions from pig manure. Similarly, reducing the concentration of dietary sulfur (S) containing amino acids and any excess S containing minerals (in the trace mineral mix) can reduce S excretion (Shurson, et al 1999). Altering the VFA and other volatile organic acids (VOC) with diet modification is more difficult. Use of low levels of fiber (soybean hulls, sugar beet pulp, wheat bran, and wheat middlings) can alter the form of excretion of N and the production of VFA (Cahn, et al 1997; Shriver, et al 2003).

Applicability:

Pigs were group-fed in facilities that represent commercial settings to determine the effects of diet manipulation on nutrient excretion, gas emissions and odors from swine buildings. The intent of this research was to demonstrate that a producer can use low nutrient excretion (LNE) diets in production settings without sacrificing animal performance or product quality, and thereby reduce the potential impact of manure excretion on air quality. Following is a brief description of the research methods and results:

A total of 1,920 pigs (equal barrows and gilts) with an average initial body weight (BW) of 5.16 kg (11.4 lb) were used in a wean-finish experiment to evaluate the effects of diet (Control (CTL) vs. LNE) on growth performance, carcass characteristics, manure excretion, and gas and odor emissions. Pigs were housed in an environmentally-controlled building in 12 identical rooms with independent ventilation, feeding systems, water, and manure storage pits. Each room housed 10 pigs per pen with 60 pigs per room. Pigs were blocked by BW and sex (10 pigs/pen; 60 pigs/room) and randomly allotted to 1 of 2 treatments (standard commercial corn-SBM control, CTL; or LNE). Pigs were split-sex and phase-fed to meet or exceed nutrient requirements (NRC, 1998). This trial consisted of five nursery phase diets and four grow-finish phase diets. The nursery phases included: 1) Pellets, a common diet for all pigs, d 0-7; 2) Phase 1, d 7-14; 3) Phase 2, d 14-28; 4) Phase 3, d 28-42; and 5) Phase 4, d 42-56. The grow-finish phases included: 1) Grower 1, d 56-84; 2) Grower 2, d 84-112; 3) Finisher 1, d 112-140; and 4) Finisher 2, d 140-152. Individual/pen body weights and pen feed consumption data were collected weekly during phase 1, then every two weeks thereafter. Four pigs from each pen were scanned ultrasonically to determine loin eye area and 10th rib backfat thickness starting at two months of age and every four weeks thereafter. At the end of the experiment, carcass data were collected at harvest on all pigs by a commercial slaughter facility. An example of CTL and LNE formulations for one phase is shown in Table 1. The LNE diets had reduced crude protein compared to the CTL diets, and included synthetic amino acids, phytase (Natuphos, BASF, New Jersery, USA), added fat, and a non-sulfur trace mineral premix. Diets were formulated based on NRC (1998) requirements for available phosphorus and true ileal digestible amino acids, while maintaining similar lysine: calorie ratios.

Table 1. Dietary Treatments for Finisher 1.

	Control		LNE	
Ingredients, %	Barrows	Gilts	Barrows	Gilts
Corn	81.05	79.27	81.66	79.68
Soybean meal	17.00	18.79	12.03	14.01
Choice white grease	------	------	4.00	4.00
Calcium carbonate	0.66	*0.65*	*0.90*	*0.90*
Dicalcium phosphate	0.70	0.69	0.34	0.33
Vitamin premix	0.10	0.10	0.10	0.10
TM premix	0.05	0.05	------	------
Non-sulfur TM premix	------	------	0.05	0.05
Phytase	------	------	0.083	0.083
Salt	0.25	0.25	0.25	0.25
Lysine-HCl	0.10	0.10	0.32	0.32
DL-methionine	------	------	0.05	0.06
L-threonine	0.01	0.02	0.12	0.12
L-tryptophan	------	------	0.02	0.02
Tylan 40	0.025	0.025	0.025	0.025
Se 600	0.05	0.05	0.05	0.05
Calculated Analysis				
ME, kcal/kg	3347	3346	3517	3517
Lysine:calorie ratio	2.101	2.235	2.101	2.235
Calcium, %	0.50	0.50	0.50	0.50
Avail. Phosphorus. %	0.19	0.19	0.19	0.19

Real-time instruments monitored NH_3, hydrogen sulfide (H_2S), carbon dioxide (CO_2), and methane (CH_4) continuously throughout the trial. Thirty nine (39) odor samples were collected at months 1, 3, and 5 of each replicate with three samples obtained from each room exhaust and three from the fresh air plenum that is common to all rooms. The three odor samples obtained from each room were collected at each measurement location simultaneously. Air samples were collected into 10-L Tedlar bags. An olfactometer (AC'SCENT International, St. Croix Sensory, Inc., St. Paul, MN) was used to evaluate each bag sample of air. All evaluations were performed by trained human panelists. Sample evaluation occurred the same day as sampling to minimize bag losses.

All data were analyzed using the GLM procedure of SAS (2006; SAS Institute Inc., Cary, NC). Pen was the experimental unit for animal performance and carcass characteristics. Manure pit was the experimental unit for manure management strategy, and room was the experimental unit for gas emissions.

Results

In the nursery phase, pigs fed the LNE diets had improved feed efficiencies (Gain: Feed) as a result of reduced average daily feed intakes (ADFI) and increased average daily gains (ADG) compared to CTL-fed pigs. By the end of the nursery period, LNE-fed pigs tended ($P = 0.09$) to be 0.98 kg (2.16 lb) heavier than CTL-fed pigs. During the nursery period, performance was similar for pigs fed LNE diets compared to the CTL diet.

Throughout the grow-finish phases, ADFI were lower ($P < 0.001$) and feed efficiencies were improved ($P < 0.001$) for LNE-fed pigs compared to CTL-fed pigs. Overall, pigs fed the LNE diet grew faster (0.998 vs. 0.965 kg/d (2.20 vs 2.13 lb/d)) ($P < 0.002$) while consuming less feed (2.55 vs. 2.77 kg/d (5.62 vs. 6.10 lb/d)) ($P < 0.001$) than CTL-fed pigs. This resulted in a better overall feed efficiency (0.39 vs. 0.35) ($P < 0.001$) for LNE-fed pigs compared to CTL-fed pigs.

Similar to live weight, carcass weights were 3.8 kg (8.4 lb) heavier ($P < 0.001$) for LNE-fed pigs (96.6 kg; 213.0 lb) compared to CTL-fed pigs (92.8 kg; 204.6 lb). Along with higher carcass weights, LNE-fed pigs had 2.2 cm (5.6 in) of extra backfat depth ($P < 0.001$) compared to CTL-fed pigs. However, there were no differences ($P > 0.10$) in carcass loin depth.

Daily excretion of dry matter (DM), N, ammonium N, phosphorus (P), potassium (K), ash, and VFA were greater for CTL-fed pigs compared to LNE-fed pigs and linearly increased over time. DM excretion increased from 0.209 kg/pig/d (0.46 lb/pig/d) during wk 8 to 0.362 kg/pig/d (0.80 lb/pig/d) during wk 22 for CTL-fed pigs and from 0.153 kg/pig/d (0.34 lb/pig/d) during wk 8 to 0.315 kg/pig/d (0.69 lb/pig/d) during wk 22 for LNE-fed pigs. The LNE-fed pigs consistently excreted ~48 g (0.11 lb) less DM per day than CTL-fed pigs. Similar to DM excretion, N excretion increased over time and was lower ($P < 0.001$) for LNE-fed pigs than CTL-fed pigs (Figure 1). Regression curves were fit to CTL ($R^2 = 0.94$) and LNE pigs ($R^2 = 0.99$) for N excretion (g/pig/d) and indicated a linear increase in N excretion with week of production. The slope of this line was greater for CTL-fed pigs (1.69) than LNE-fed pigs (1.10) indicating that the difference in N excretion between CTL and LNE fed pigs increased as the pigs grew older. Ammonium N, which can be readily lost as NH_3 followed a similar pattern to total N. Based on regression equations, pigs fed LNE diets consistently excreted 26-28% less ammonium N than CTL-fed pigs. In another study, by using crystalline amino acids to reduce dietary crude protein concentration in corn-soybean meal diets, N excretion was reduced 20 to 30% without influencing growth performance, carcass value or cost of production. Total mineral excretion as estimated by ash content of the manure increased with week of production ($P < 0.001$) and was lower ($P < 0.001$) for LNE-fed pigs than CTL-fed pigs. Specifically, P excretion (Figure 2) was 40% lower ($P < 0.001$) at all time points for LNE-fed pigs compared to CTL-fed pigs, while K excretion was 17-18% lower ($P < 0.001$) for LNE-fed pigs compared to CTL-fed pigs. Volatile fatty acids which have been attributed to various odorous compounds originating in swine manure increased ($P < 0.001$) in amount/pig/d as the pigs got older and heavier, and were greater ($P < 0.001$) for CTL-fed pigs compared to LNE-fed pigs (Figure 3). Excretion of acetate, propionate valerate, and isovalerate were approximately 26, 26, 36, and 47% lower ($P < 0.001$), respectively, for LNE-fed pigs compared to CTL-fed pigs, and did not change with time. However, since excretion of these compounds linearly increased over time, the actual reduction in excretion of LNE-fed pigs compared to CTL-fed pigs increased from 5.9-16.4, 2.0-4.2, 0.57-1.38, and 0.88-1.12 mmole/pig/d for acetate, propionate, valerate, and isovalerate, respectively from wk 8 to 22. For butyrate and isobutyrate , the slope of the regression line was smaller for CTL-fed pigs over time than for LNE-fed pigs. Therefore, while excretion of butyrate and isobutyrate was lower for LNE-fed pigs at all time points, the difference in excretion decreased from 29-15% for butyrate and 30-21% for isobutyrate from wk 8 to 22.

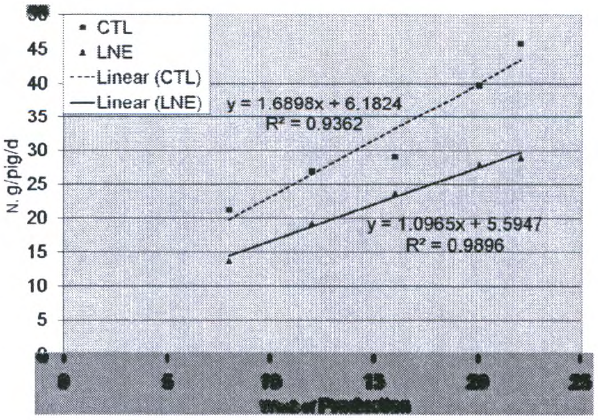

Figure 1. Effect of LNE diet on total N excretion (Diet effect, $P < 0.001$; Week effect, $P < 0.001$; Diet*Week, $P > 0.10$).

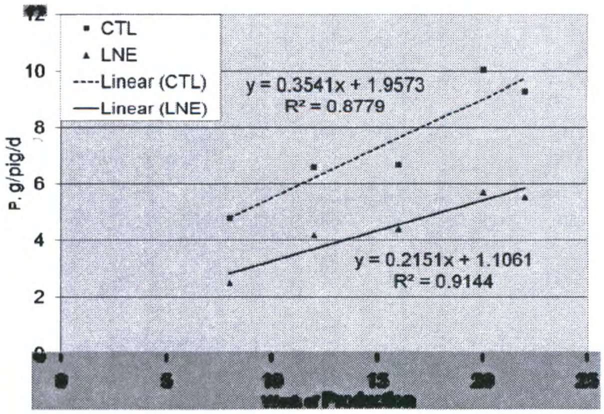

Figure 2. Effect of LNE diet on P excretion (Diet effect, $P < 0.001$; Week effect, $P < 0.001$; Diet*Week, $P > 0.10$).

Pigs fed LNE diets reduced aerial NH_3 emissions over the wean-finish period by 13.6% ($P<0.001$) compared to pigs fed CTL diets (Figure 4). Aerial H_2S and SO_2 concentration were not different ($P>0.10$) among dietary treatments even though LNE diets were formulated with a non-sulfur trace mineral premix. Air concentration data was also affected by wk of production, except for aerial SO_2 concentration. Aerial NH_3, H_2S, and CH_4 concentrations were increased by 43.4, 68.3, and 29.0%, respectively, from wk 4 to wk 16 ($P<0.001$). Conversely, the concentration of CO_2 was reduced by 13.6% during wk 20 compared to wk 4 ($P<0.001$). There was no significant effect of dietary treatment on odor emissions.

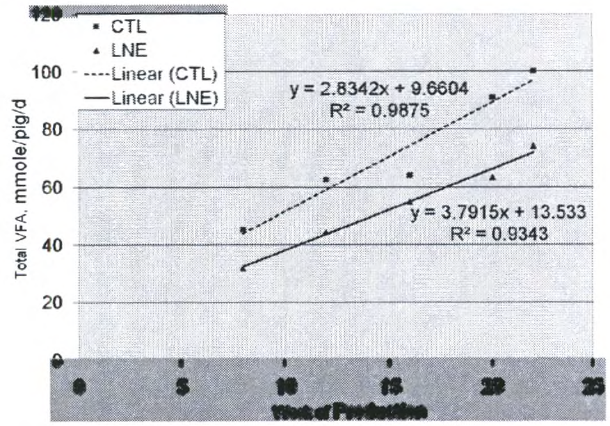

Figure 3. Effect of LNE diet on VFA excretion (Diet effect, $P < 0.001$; Week effect, $P < 0.001$; Diet*Week, $P > 0.10$).

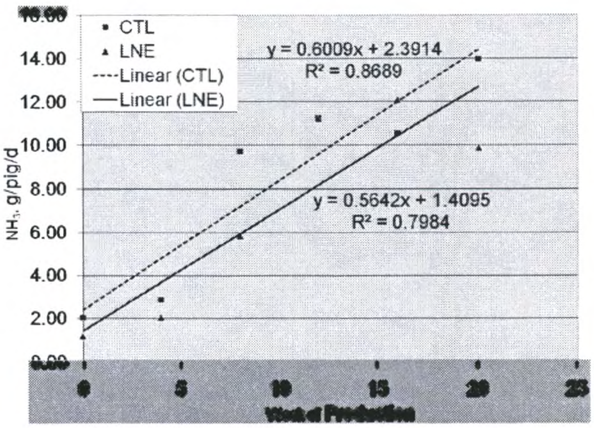

Figure 4. Effect of LNE diet on NH_3 emission (Diet effect, $P > 0.10$; Week effect, $P < 0.001$; Diet*Week, $P > 0.10$).

Limitations:

The major limitation of diet modification techniques is the potential impact of utilizing specific feed ingredients, synthetic amino acids or feed additives on the cost of the diet. Since feed is 60-70% of the out-of-pocket cost of pork production, producers want to minimize feed costs without sacrificing pig performance. Therefore, nutritionists and pork producers may be resistant to decreasing safety margins and using alternative feed ingredients. In addition, the availability of these feed ingredients to produce consistent diets is important for implementation. Lysine, threonine and methionine are readily available and economical; the cost and availability of tryptophan is currently cost prohibitive. Similarly, the lack of availability and potential higher cost of non-sulfate mineral sources for pig diets may not be practical. If fiber is included in the finishing pig's diet from 7 to 10%, fat may need to be added to the diet to supply energy to support pig performance when feeding fiber sources.

From a practical standpoint, diet modification can significantly reduce NH_3, H_2S, VFA, and VOC emissions, but will not reduce them to zero. Feeding highly digestible ingredients to pigs is theoretically possible; however, the availability and costs of these diets are prohibitive. However, with the potential for genetically altering feed ingredients, formulating more nutrient digestible and efficient diets may be possible in the future. Inclusion of byproduct feeds such as distillers dry grains with solubles may create a greater emission of NH_3 and H_2S because of the high concentrations of protein and sulfur compounds in this ingredient. Care is needed in selecting other byproduct feeds for pig diets and their potential impacts on nutrient excretion and air emissions.

Cost:

Economic analysis of CTL and LNE formulations proceeded in three fashions. The cost per kg of feed was computed using average corn, soybean meal, and hog prices for the last two years and current prices for other ingredients. Carcass value was based on the Indiana Packers Carcass Buying Program (http://www.inpac.com/proc/carcass.html) as of March 2008. The cost of feed per kg was essentially constant for all formulations and phases. While the cost of feed is important it does not encompass all of the economic decisions associated with diet manipulation. The implications of animal performance in terms of feed efficiency and carcass quality must also be considered. In the context of a production contract, a contractor who owns the pigs makes feeding decisions that are independent from a grower's manure management constraints or opportunities. Thus, the net return over feed costs is the determining factor in diet choice. Using data from this trial, the higher gain to feed ratio for the LNE-fed pigs regardless of sex favors the use of LNE diets from a net return over feed cost standpoint. The estimated economic benefits range from $8.92 per head for barrows to $10.82 per head for gilts. A portion of this difference is the result of a common slaughter age (153 days) used in all treatments. In all likelihood, the economically optimal slaughter age for CTL animals would be greater than that for the faster growing LNE animals. Allowing the CTL animals more time to reach a heavier carcass would result in more net return over grow-finish feed costs and narrow the economic gap delineated above. However, with higher feed ingredient costs, larger facilities investments, and rigidly fixed farrowing schedules, it is likely that LNE diets would still be preferred to the CTL.

The manure management and diet choice decisions are not decoupled on all farms. Independent producers make decisions about cropping patterns, manure management, and crop fertilization in conjunction with their choice of feed rations for livestock. The model developed by Yap et al. (2004) and recently updated by Hollas (2008) for a representative independent Indiana farm combines these decisions to choose the mix of farm activities that maximizes the whole farm net return over variable costs. This model requires input on a finite set of formulation alternatives and clearly the CTL and LNE formulations in this study are not inclusive of all potentially optimal formulations. However, applying the Yap et al. model (limiting land application of manure to the P requirement of the crops) to the two formulation choices for both gilts and barrows further reinforces the potential economic benefits of the LNE diets. While the optimal cropping pattern does not change when the model is forced to use the CTL formulations, the cost of manure disposal and feed increases, leading to economic gains from LNE formulations for a fixed schedule grow-finish system that is optimized for the faster growing LNE-fed animals. The economic benefits for LNE diets range from $7.21 per pig space for gilts to $8.79 per pig space for barrows.

Implementation:

Dietary modifications using the techniques described are very effective in reducing environmental impacts of pork production. As a result, operations producing a majority of the pigs are using these techniques on their commercial operations. The implementation of LNE diets has become more commonplace recently because of the greater availability and lower cost of synthetic amino acids (lysine, threonine methionine), phytase, and various fiber sources. On-farm studies at commercial operations (1,000 head grow-finishers) have proven that these mitigating technologies work well. Ammonia emissions have been reduced consistently from 30 to 50% on commercial farms and H2S has been reduced by 20 to 30%. The degree of mitigating response depends upon the status of the initial commercial diet that was modified on the farm. There is still a need to educate and encourage producers to implement current diet modification technologies along with other feed management and production management practices.

Technology Summary:

Odor and gas emissions from pork operations primarily come from the anaerobic degradation of nutrients in manure. Nutrients excreted by the pig are from undigested feed ingredients and losses from normal metabolism. Since the pig is the initial point source of nutrients excreted and resultant gas and odor emissions, diet modification has the potential to reduce nutrients excreted and thereby reduce gas and odor emissions. A wean-finish pig study was conducted to determine the effect of feeding a low nutrient excretion diet on nutrient excretion, gas and odor emissions. Overall, pigs fed the LNE diet grew faster while consuming less feed than CTL-fed pigs. This resulted in a better overall feed efficiency for LNE-fed pigs compared to CTL-fed pigs. Similar to live weight, carcass weights were heavier for LNE-fed pigs compared to CTL-fed pigs. Daily excretion of dry matter (DM), N, ammonium N, phosphorus (P), potassium (K), ash, and VFA were greater for CTL-fed pigs compared to LNE-fed pigs and linearly increased over time. Pigs fed LNE diets consistently excreted 26-28% less ammonium N than CTL-fed pigs. Phosphorus excretion was 40% lower for LNE-fed pigs compared to CTL-fed pigs, while K excretion was 17-18% lower for LNE-fed pigs compared to CTL-fed pigs. Pigs fed LNE diets reduced aerial NH_3 emissions over the wean-finish period by 13.6% compared to pigs fed CTL diets. Aerial H_2S and SO_2 concentration were not different among dietary treatments even though LNE diets were formulated with a non-sulfur trace mineral premix. There was no significant effect of dietary treatment on odor emissions.

The major limitation of diet modification techniques is the potential impact of utilizing specific feed ingredients, synthetic amino acids or feed additives on the cost of the diet. Since feed is 60-70% of the out-of-pocket cost of pork production, producers want to minimize feed costs without sacrificing pig performance. Therefore, nutritionists and pork producers may be resistant to decreasing safety margins and using alternative feed ingredients. In addition, the availability of these feed ingredients to produce consistent diets is important for implementation. An economic analysis was conducted with this study and the cost per kg of feed was computed using average corn, soybean meal, and hog prices for the last two years and current prices for other ingredients. Carcass value was based on the Indiana Packers Carcass Buying Program (http://www.inpac.com/proc/carcass.html) as of March 2008. The cost of feed per kg was essentially constant for all formulations and phases. The higher gain to feed ratio for the LNE-fed pigs regardless of sex favors the use of LNE diets from a net return over feed cost standpoint. The estimated economic benefits range from $8.92 per head for barrows to $10.82 per head for gilts. A model used to include the decisions about cropping patterns, manure management, and crop fertilization in conjunction with their choice of feed rations for livestock further reinforces the potential economic benefits of the LNE diets. The economic benefits for the LNE diets range from $7.21 per pig space for gilts to $8.79 per pig space for barrows.

Additional Resources:

Purdue Swine Research Reports accessed at http://www.ansc.purdue.edu

Acknowledgments:

Partial funding through grants from USDA-NRI and National Pork Board grants is gratefully acknowledged and appreciated. The assistance of Dan Kelly, Meredith Cobb, Claude Diehl, Maria Walsh, Kari Saddoris, and Lindsay Sims with this research is greatly appreciated.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
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Effects of Dietary Manipulation on Ammonia Emissions

Scott Carter, Mariela Lachmann, and Justin Bundy
Oklahoma State University

Species:	Swine
Use Area:	Animal Housing
Technology Category:	Diet Modification
Air Mitigated Pollutants:	Ammonia

Description:

Ammonia emission from swine housing is primarily dependent on the amount of nitrogen excreted by swine. Nitrogen excretion is influenced by dietary protein level, digestibility of the dietary protein, amino acid balance, and genetics of the pig. A portion of the dietary protein consumed by the pig is excreted in the feces and urine. Fecal nitrogen is predominantly composed of undigested dietary protein. Urinary nitrogen is excreted primarily in the form of urea. Urea, when combined with feces in the pit, is enzymatically digested to ammonia. Ammonia emission from swine housing is an environmental concern and improvements in the utilization of dietary protein can provide benefits of decreasing ammonia emissions.

The most widely used method to decrease nitrogen excretion and, therefore, ammonia emission from swine housing is the use of lower protein diets with amino acid supplementation. Lowering crude protein content of the diet with amino acid supplementation for growing-finishing pigs has been shown to decrease nitrogen excretion and ammonia concentration of the manure (Sutton et al., 1999). Kerr et al. (1995) reported an 8 to 10% decrease in nitrogen excretion by swine for every 1 percentage unit reduction in dietary crude protein. Additionally, marked decreases in ammonia concentration or emission in anaerobically-stored manure in simulated pits have been reported (Sutton et al. 1999).

Another potential mechanism to further reduce ammonia concentration or emission from swine housing is the use of fermentable carbohydrates (fiber) in the diet. Fiber addition to diets has been shown to alter the proportion of nitrogen excreted in the feces and urine (Cahn et al, 1998; Shriver et al., 2003). By increasing the proportion of nitrogen excreted in the feces and reducing the proportion of nitrogen excreted in the urine as urea, ammonia emissions can be reduced (Sutton et al., 1999). While numerous studies have reported decreases in nitrogen excretion and(or) reductions in ammonia emission due to dietary manipulation, a majority of these studies were performed using individual pigs and simulated manure pits.

Lachmann et al. (2007) reported a 31% decrease in total nitrogen excretion, a 37% reduction in ammonium nitrogen concentration of the slurry, and a 56% reduction in ammonia emissions for pigs fed a diet with crude protein concentration reduced by three percentage units with amino acid supplementation during a 110-day finishing period. Bundy et al. (2008) reported similar effects for pigs fed a diet with crude protein reduced by three percentage units. Additionally, in this study, the addition of a fiber source (soybean hulls) further reduced ammonium nitrogen concentration in the slurry, and a further numerical decrease in ammonia emissions was noted during a 112-day finishing period.

Additional benefits of lowering dietary crude protein and adding fiber to diets reported by Lachmann et al. (2007) and Bundy et. al. (2008) included:

- Decreased pH of the slurry
- Decreased concentration of ammonia in the swine house, better environment for workers
- No effect on growth performance and carcass traits

Mitigation Mechanism:

Ammonia volatilization from the waste treatment system in swine houses is dependent on temperature, air velocity, moisture content, waste storage system (deep pit vs. shallow pit), pH, and ammonium concentration. Lowering crude protein content of the diet with amino acid supplementation reduces nitrogen excretion. The decrease in nitrogen excretion reduces the concentration of ammonium in the slurry which, in turn, decreases ammonia emission.

Additionally, the reduction in ammonium concentration of the slurry also reduces slurry pH which affects ammonia volatilization. Addition of fiber sources to the diet reduces urinary urea excretion which can be degraded enzymatically to ammonia. The reduction in crude protein content or addition of fiber sources to swine diets can reduce or change nitrogen excretion patterns resulting in marked decreases in ammonia emissions for pigs housed in facilities with shallow pit, pull-plug waste storage systems. Furthermore, the decrease in ammonia improves indoor air quality for not only the workers, but also for the pigs.

Applicability:

The use of dietary manipulation is an effective method to reduce ammonia emissions from swine in the finishing phase. Lowering crude protein content of the diet by 3 percentage units with appropriate amino acid supplementation can reduce ammonia emission by over 50% compared with pigs fed typical corn-soybean meal diets from 28 to 118 kg (65 to 260 lb). Moreover, addition of a fiber source, such as soybean hulls, to a low protein diet can further reduce ammonia emissions.

Limitations:

The use of low protein diets with amino acid supplementation is dependent on knowledge of the amino acid requirements of the pig. Failing to meet the lysine requirement or inadequate supplementation of other amino acids in relation to lysine when using low protein diets may decrease growth performance and carcass merit of finishing pigs. Lowering crude protein by up to 3 percentage units with adequate amino acid supplementation does not affect growth performance or carcass traits. However, further reductions in crude protein (>3%) have been reported to decrease carcass merit in some studies.

The use of fiber in diets is dependent on accurate nutrient analysis of the source in order for optimum diet formulation. Also, the use of fiber (soybean hulls) in diets is limited to approximately 10 to 15% of the diet. Dietary levels greater than 10 to 15% could potentially reduce growth performance. It is also important to note that addition of fiber can potentially increase dry matter excretion which translates to an increase in total solids content of the slurry.

Additionally, the cost of crystalline amino acids must be weighed when deciding whether to incorporate low protein diets in the feeding program of finishing pigs. It is recommended that producers utilize a nutritionist to formulate low protein diets or diets containing fiber in order to reduce the risk of effects on growth performance and(or) carcass traits and to minimize diet costs.

Cost:

In the studies discussed here, there were no effects of dietary treatment on pig performance and carcass traits. Thus, implementation decisions are based on ingredient costs. Formulation of low protein diets involves the partial removal of soybean meal from the diet accompanied by replacement with corn and crystalline amino acids (lysine HCl, DL-methionine, L-threonine). Therefore, evaluation of implementation cost weighs the decrease in soybean meal costs versus the increase in corn and amino acid costs within the diet. Using March 2008 ingredient costs of $0.044/kg ($5.40/bu) for corn and $0.077/kg ($340/ton) for dehulled soybean meal, the diet costs for the two treatments used in this study were $0.298/kg ($0.135/lb) for the control diet and $0.295/kg ($0.134/lb) for the low protein, amino acid supplemented diet. Cost of gain equaled $0.841 and 0.823/kg ($0.381/lb, $0.373/ lb) and total feed cost for the finishing period (28 to 118 kg) equaled $70.9 and $68.6/finished pig, respectively, for the control and low protein, amino acid supplemented diet.

Implementation:

The results reported in this document are based on two experiments using finishing pigs (Bundy et al., 2008; Lachmann et al., 2007). In both experiments, crossbred pigs initially weighing 28 kg (65 lb) were housed in a finisher building containing four identical rooms, each with a shallow pit, pull plug waste storage system. Pigs and feeders were weighed weekly during a 16-week finishing period in order to determine growth performance. Slurry in the pits was collected each week during the 16-week period and used to calculate nutrient excretion. Additionally, ventilation rate and ammonia concentration of the exhaust air was monitored continuously for each room during the finishing period. Ventilation rate and ammonia concentrations were used to calculate emission rates for ammonia.

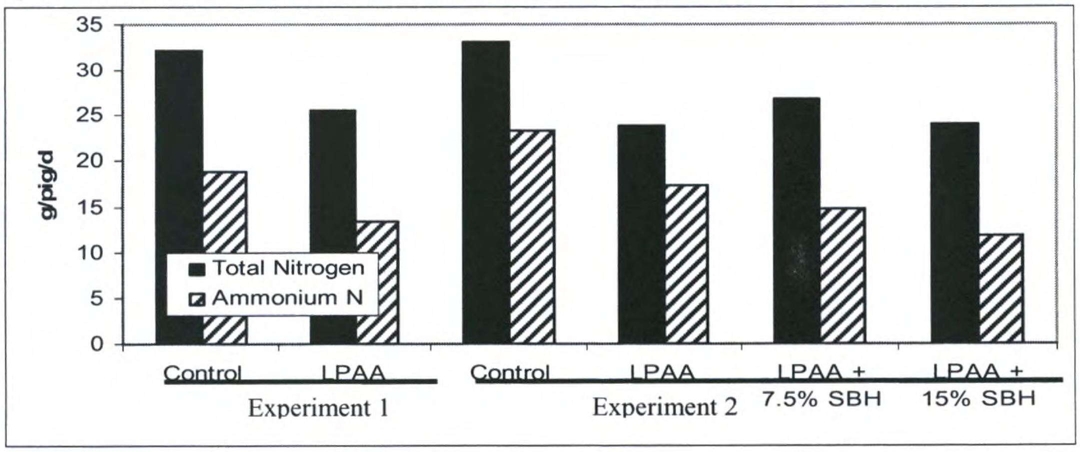
In each experiment, pigs were fed in four dietary phases during the finishing phase. In both experiments, a similar control and low protein, amino acid supplemented diet was fed (Table 1). The control diet was a typical, fortified corn-soybean meal based diet formulated to meet the lysine requirement of the pig. In the low protein, amino acid supplemented diet, crude protein concentration was reduced by 3 percentage units and lysine was added to maintain lysine levels similar to the control diet. Additional amino acids (threonine, methionine) were added to this diet on an ideal basis. Additionally, phosphorus concentration was reduced by 0.10% and phytase was added. In Experiment 2, two additional dietary treatments were employed. Soybean hulls were added to the low protein diet at 7.5 and 15% in order to examine the effects of fiber addition to the diet.

Table 1. Dietary composition of the control and low protein, amino acid supplemented (LPAA) diets for the four dietary phases used in Exp. 1 and 2 (as-fed basis)

	Phase 1		Phase 2		Phase 3		Phase 4	
Ingredient, %	Control	LPAA	Control	LPAA	Control	LPAA	Control	LPAA
Corn	65.72	74.24	71.30	79.90	76.71	85.37	80.54	89.16
SBM, 48% CP	29.11	20.58	23.66	15.07	18.30	9.73	14.58	6.12
L-lysine		0.27		0.28		0.27		0.27
DL-methionine		0.01						
L-threonine		0.08		0.09		0.07		0.04
L-tryptophan		0.01		0.01		0.01		
Soybean oil	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Dicalcium P	0.61	0.26	0.54	0.20	0.47	0.12	0.39	0.04
Limestone	0.97	0.98	0.94	0.90	0.93	0.88	0.90	0.85
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin mix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
TM mix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic	0.10	0.1	0.10	0.10	0.10	0.10	0.10	0.10
Phytase		0.02		0.02		0.02		0.02
Diet cost, $/lb	0.141	0.139	0.136	0.136	0.132	0.133	0.130	0.126
Calculated composition, %								
ME, kcal/kg	3483	3487	3490	3494	3494	3501	3499	3508
CP, %	19.3	16.3	17.2	14.2	15.1	12.1	13.6	10.6
Lysine, %	1.05	1.03	0.90	0.88	0.75	0.73	0.65	0.63
Ca, %	0.60	0.50	0.56	.044	0.52	0.40	0.48	0.36
P, %	0.50	0.40	0.46	0.36	0.43	0.33	0.40	0.30

In Experiment 1, feeding the low protein, amino acid supplemented diet reduced nitrogen excretion by 31%, ammonium nitrogen concentration of the slurry by 37%, and reduced ammonia emissions by 56% (Figure 1). In Experiment 2, similar results decreases in nitrogen excretion and ammonium nitrogen concentration of the slurry were observed for pigs fed the low protein, amino acid supplemented diet (Figure 1). Addition of soybean hulls to the low protein, amino acid supplemented diet in Experiment 2 did not affect total nitrogen excretion, but further reduced ammonium nitrogen concentration of the slurry.

Figure 1. Total nitrogen and ammonium nitrogen excretion for pigs fed the dietary treatments in Experiment 1 and 2.



Ammonia emissions for pigs in each experiment and housed in this shallow pit, finisher building is shown in Table 2. Air ventilation rate was similar between rooms within each experiment. Ammonia concentration (mg/m3), emission rate (mg/min), and total emission on a per pig basis were reduced in each experiment by feeding the low protein, amino acid supplemented diet. These reductions in ammonia emission were obtained without any effect on growth performance, carcass traits, or feed costs.

Table 2. NH_3 emissions for pigs fed the dietary treatments in each experiment during a 116-d finishing period.

	Experiment 1[a]		**Experiment 2[b]**			
	Control	**LPAA**	**Control**	**LPAA**	**LPAA + 7.5% SBH**	**LPAA + 7.5% SBH**
NH_3, mg/m^3	0.863	0.418	2.52	1.76	1.27	1.29
NH_3, mg/min	29.78	12.80	71.3	36.4	32.5	30.2
NH_3, g/pig/d	2.32	1.02	1.95	0.99	0.88	0.82
NH_3, g/d-AU	15.5	6.4	11.85	6.04	5.15	4.66

[a] Experiment 1 utilized 20 pigs per room and was conducted from July through November.

[b] Experiment 2 utilized 22 pigs per room and was conducted from January through April.

Additionally, in these studies, growth performance, carcass traits, or measures of carcass composition were not affected by dietary treatment. Thus, producers that implement the use of low protein, amino acid supplemented diets to decrease nitrogen excretion and mitigate ammonia emissions should not experience effects on growth performance, carcass traits, or feed costs of finishing pigs. However, these results are dependent on correct diet formulation and not exceeding a 3 percentage unit reduction in crude protein.

Technology Summary:

The use of low protein, amino acid supplemented diets is an effective method to decrease nitrogen excretion and mitigate ammonia emissions from swine finisher facilities. Reduction of protein in the diet reduces total nitrogen excretion by the pig. The decrease in total nitrogen excretion (specifically urea nitrogen) reduces the substrate available for ammonia volatilization. Additionally, slurry pH is reduced which also decrease ammonia emissions. Addition of fiber to low protein, amino acid supplemented diets has the potential to further decrease urinary urea nitrogen excretion and, thus, ammonia emissions. These results can be obtained without adverse effects on growth performance and carcass traits of finishing pigs. However, these results are dependent upon adequate amino acid supplementation to the diet. With correct dietary formulation, increases in diet cost can be avoided and, thus, feed cost/pig is similar to a conventional corn-soybean meal diet. Producers are urged to work with a swine nutritionist before implementing these types of diet to decrease the risk of potential negative effects on growth performance, carcass traits, or diet cost. Also, further reductions in dietary crude protein beyond 3 percentage units should be discussed with a nutritionist. Dietary manipulation is an effective method to mitigate ammonia emissions and should be considered as a first line of defense in a whole farm approach to mitigating ammonia emissions.

Additional Resources:

Diet effects on manure nutrients http://www.pork.org/porkscience/Environment/ManureMgmt.aspx?c=DietEffects#one

Managing nutrient excretion and odor in pork production through nutrition http://www.porkgateway.org/

Understanding and applying nutrition concepts to reduce nutrient excretion in swine
http://mark.asci.ncsu.edu/Nutrition/Environ/concepts.pdf

Acknowledgments:

Project support was provided by the National Pork Board, USDA/CSREES, and the Oklahoma Agricultural Experiment Station.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
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U.S. Pork Center of Excellence

Dietary Manipulation to Reduce Ammonia Emission from High-Rise Layer Houses

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Species:	Poultry (Layers)
Use Area:	Animal Housing
Technology Category:	Diet Modification
Air Mitigated Pollutants:	Ammonia

Description:

Ammonia (NH_3) generation from poultry production is a result of microbial decomposition of uric acid and undigested nitrogen (N) in bird feces. Ammonia emission is associated with N content of the feces, which is influenced by feed composition and feed conversion efficiency of the bird. To reduce N content in feces, ration may be formulated with reduced dietary crude protein (CP) and supplemented with limiting amino acids (AA) to match bird dietary requirements, thereby improving digestive conversion efficiency. A dietary manipulation experiment with hens fed properly formulated lower CP diets was conducted for a full year to evaluate NH_3 emission from commercial layer houses.

Mitigation Mechanism:

The lower CP diet (LCP) was tested against an industry standard or control (Ctrl) diet in four high-rise (HR) laying-hen (Hy-Line W-36) houses at a commercial layer facility in Iowa to study the effect of diet manipulation on NH_3 emissions. Two of the HR houses received a standard CP ration (Ctrl) and the other two received a LCP ration supplemented with amino acids (AA). Hence, the experiment had two dietary regimens with two replicates each.

In general, the LCP diet had 0.4 to 1.2% lower CP than the Ctrl diet during various feeding phases. Soy content was reduced in the LCP diet, and crystalline AA DL-methionine, L-lysine.HCL and L-threonine were supplemented so that these essential AA were at the same levels in both diets for each corresponding feeding phase. Tryptophan and isoleucine in the LCP diet were slightly lower than those in the Ctrl diet (difference ranged from 0.02% to 0.06%).

Daily NH_3 emission rate (ER) for houses with the LCP diet averaged 0.80 g d^{-1} hen^{-1} (annual ER: 292 g hen^{-1}), as compared with 0.90 g d^{-1} hen^{-1} (Annual ER: 329 g hen^{-1}) for the Ctrl diet houses (Table 1). Hence, NH_3 ER decreased by 11% with up to 1.2% reduction in dietary CP. No significant difference was found between the two diets in weekly hen-day egg production (80.3% for Ctrl vs. 80.2% for LCP) (Fig. 1) or case weight (47.7 lb $case^{-1}$ for Ctrl vs. 48.3 lb $case^{-1}$ for LCP). Therefore, the results indicate that dietary manipulation provides a viable means to reduce NH_3 emission from laying hen operations.

Applicability:

This mitigation technology was tested with Hy-Line W-36 laying hen birds from 20 to 108 weeks of age.

Limitations:

Crude protein (amino acids) in the diet can only be reduced to the level where the next essential amino acids becomes limiting, otherwise it will adversely affect bird performance. The discussed study utilized diets ranging from 0.4 to 1.2% lower CP than the standard or Ctrl diet during various feeding phases to achieve approximately 11% of ammonia emission reduction.

Table 1. Effect of lower crude protein (LCP) diet on ammonia emission rate (ER) from HR layer houses in Iowa

NH_3 ER in g/d-hen (range)		NH_3 ER reduction by the LCP diet
Standard (Ctrl) diet	Lower CP (LCP) diet	
0.90 (0.24 – 1.60)	0.80 (0.19 – 1.37)	11%

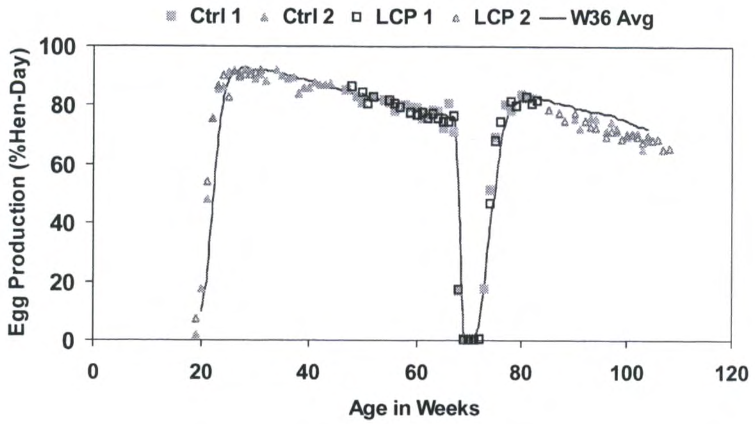

Figure 1. Egg production of birds receiving Standard (Ctrl) or lower CP (LCP) diets. Solid line represents average production performance of Hy-Line W-36 birds.

Cost:

Table 2 lists the cost comparison of a sample dietary formulation of the LCP and Ctrl diets. When the study was conducted in 2003, the costs of 1000 kg of feed were $115.75 and $116.22 for the LCP and Ctrl rations, respectively, based on an estimated corn and soybean prices of $116 and $210 /1000kg. The cost of the same LCP dietary formulation is 1.2% less (2008 prices) than that of the standard dietary formulation due to reduced grain portions, which is especially relevant with the current higher grain costs (corn, soybean, etc.). The costs of 1000 kg of feed are $235.44 and $238.47 for the sample LCP and Ctrl rations based on the 2008 prices, respectively.

Implementation:

Sample dietary formulation of the LCP and Ctrl diets and their nutrient compositions are provided in Tables 2 and 3.

Table 2. Sample dietary formulations of the lower crude protein (LCP) and standard (Ctrl) diets and cost comparison (February 2008 cost basis).

Ingredient	Weight (kg)		Unit price ($/1000kg)	Formulated Cost ($)	
	LCP	Ctrl		LCP	Ctrl
Corn	581.787	552.333	195.00	113.45	107.70
Soybean 48	248.262	275.039	380.00	94.34	104.51
Feed fat	40.840	45.153	255.00	10.41	11.51
Alimet	2.155	1.941	1,820.00	3.92	3.53
Limestone	98.997	98.973	19.00	1.88	1.88
Dicalcium phosphate	21.086	20.850	225.00	4.74	4.69
Salt	4.116	4.111	40.00	0.16	0.16
Vit+min premix	1.100	1.100	3,098.79	3.41	3.41
Choline chloride	0.250	0.250	648.79	0.16	0.16
Natuphos	0.250	0.250	3,578.79	0.89	0.89
L-lysine HCl	0.727		1,600.00	1.16	
L-threonine	0.429		2,100.00	0.90	
Total weight (kg)	1,000.000	1,000.000			
Total Cost of 1000kg of feed ($)				235.44	238.47

Table 3. Dietary nutrient composition of the sample formula for the lower CP (LCP) and standard or control (Ctrl) diets (%, unless otherwise noted)

Nutrient	LCP	Ctrl
Dry matter	89.952	90.038
Crude protein	16.666	17.610
Fat	6.966	7.340
Ash	14.571	14.662
Crude fibre	2.405	2.480
Nitrogen	2.714	2.863
AMEn (kCal/kg)	2,925.000	2,925.000
TMEn (kCal/kg)	3,047.290	3,048.971
Lysine	0.950	0.966
Methionine	0.466	0.460
Methionine+cystine	0.750	0.757
Cystine	0.284	0.297
Threonine	0.680	0.680
Isoleucine	0.700	0.749
Tryptophan	0.191	0.206
Arginine	1.084	1.164
Valine	0.785	0.832
Glycine	0.698	0.743
Glycine+serine	1.538	1.635
Histidine	0.467	0.493
Leucine	1.524	1.592
Phenylalanine	0.845	0.898
Phenyl.+tyrosine	1.488	1.580
Serine	0.839	0.892
Tyrosine	0.643	0.683
TEAA	10.907	11.413
Calcium	4.250	4.250
Phosphorous	0.703	0.709
Avail. phosphorous	0.480	0.480
Sodium	0.190	0.190

Technology Summary:

Utilization of lower crude protein with supplemented essential amino acids is a source reduction method to mitigate ammonia emission from laying hen production facilities. Lower N excretion in the bird feces due to lower total N intake can result in lower NH_3 emission from the production system. The 0.4 to 1.2% lower CP than the Standard diet during various feeding phases used in the above study resulted in about 11% ammonia emission reduction. Formulation based on nutritional requirement at different feeding phases is required to achieve emission reduction without affecting bird performance, i.e. egg production and case weight. The cost of using the lower CP diet is about 1% lower than that of using the standard diet.

Additional Resources:

Y. Liang, H. Xin, E. F. Wheeler, R. S. Gates, H. Li, J. S. Zajaczkowski, P. A. Topper, K. D. Casey, B. R. Behrends, D. J. Burnham, F. J. Zajaczkowski 2005. Ammonia emissions from U.S. laying hen houses in Iowa and Pennsylvania. Trans. ASABE. 48(5):1927-1941.

Acknowledgments:

Financial support was provided by the Initiative for Future Agriculture and Food Systems (IFAFS) Grant No. 2001-52103-11311 from the USDA-CSREES, the Iowa Egg Council, and the Center for Advanced Technology Development. We sincerely thank the cooperative company and farm staff for their support and cooperation throughout this study. Moreover, we wish to thank Ajinomoto Heartland Inc. for providing the feed ingredients for the diet manipulation evaluation.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
Sponsored by:
NRI Air Quality Extension & Education
Iowa Farm Bureau Federation
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Dietary Manipulations to Lower Ammonia Emission from Laying-Hen Manure

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Species: Poultry (Layers)
Use Area: Animal Housing
Technology Category: Dietary Modification
Air Mitigated Pollutants: Ammonia

Description:

Ammonia emission is a major environmental concern for egg producers. The nutrient composition and chemical characteristics of an animal's diet influence nutrient composition and characteristics of the manure and research has shown that adjusting the laying hens' diet can lower ammonia emission from the manure. The dietary manipulation techniques considered in this paper include:

- Reduced crude protein diets;
- Inclusion of high-fiber ingredients (e.g., corn distiller's dried grains with solubles [DDGS], wheat middlings, or soybean hulls); and
- Inclusion of EcoCal™—a proprietary mixture of calcium sulfate (gypsum) and zeolite.

Mitigation Mechanism:

Diets with reduced crude protein contents have been used successfully to lower ammonia emission from pig manure (van der Peet-Schwering et al., 1996) and laying hen manure (Liang et al., 2005). Animals can only perform (whether egg production or muscle growth) to the level of the first limiting amino acid in their diet. Amino acids supplied above the level of the first-limiting amino acid cannot be used and the nitrogen is therefore excreted in the urine. A reduced crude protein diet is typically formulated by including crystalline amino acids such that the inclusion of protein-supplying ingredients (e.g. soybean meal) can be decreased while still maintaining a nutritionally adequate diet. This technique allows the amino acid content of the diet to more closely resemble the amino acid requirement of the animal, thereby limiting the amount of excess nitrogen that must be excreted. In a field-scale study reported by Liang et al. (2005), laying hen diets were formulated to contain one percentage unit lower crude protein compared to a control diet and resulted in a 10% decrease in ammonia emission (Table 1). The study involved 4 high-rise laying-hen houses, each containing approximately 75,000 hens. Two houses were assigned to a standard diet and two houses were assigned to a reduced crude protein diet and emissions were measured over one year.

High-fiber ingredients are typically not included in diets for monogastric animals (i.e., pigs and poultry). However, research in Europe showed that including fiber in pig diets lowered ammonia emission from manure slurry (Kruezer and Machmuller, 1993; Tetens et al., 1996; Cahn et al., 1996; Shriver et al., 2003). Our group conducted an experiment to evaluate the effect of including high-fiber ingredients (i.e., corn DDGS, wheat middlings, or soybean hulls) in laying-hen diets on ammonia emission and found that high-fiber ingredients led to a decrease in ammonia emission from laying-hen manure (Roberts et al., 2007). Including 10% corn DDGS caused a 41% decrease in ammonia emission, 7.3% wheat middlings caused a 38% decrease in ammonia emission, and 4.8% soybean hulls caused a 27% decrease in ammonia emission from the manure. Our hypothesis of this mechanism is two-fold: 1. fiber provides energy to bacteria in the lower gastrointestinal tract where the bacteria use nitrogen, that would otherwise be excreted as uric acid, for bacterial protein synthesis; and 2. the bacterial metabolism produces short-chain fatty acids that lower manure pH, thereby shifting ammonia (NH3) to ammonium (NH4+), which is less volatile. The results of the experiment showed that the manure pH was lower from the fiber-fed hens, but it was not clear if nitrogen repartitioning from uric acid to bacterial protein occurred. This laboratory-scale study involved 128 cages of hens (2 hens per cage), each assigned to a control, corn DDGS, wheat middlings, or soybean hulls diet. Further research is continuing to investigate the effects of corn DDGS on ammonia emission from laying-hen manure and to elucidate the mechanism.

Our research group is currently working on two separate field-scale studies, each involving multiple high-rise houses, to determine the effect of dietary corn DDGS on ammonia emission under commercial production conditions. EcoCaltm is a proprietary mixture of calcium sulfate (i.e., gypsum) and zeolite. Calcium sulfate is added to the diet as an acidifier, replacing part of the dietary calcium carbonate (i.e., limestone). As described in the previous paragraph, lower manure pH shifts ammonia to ammonium, which is less volatile and will tend to stay in the manure rather than escaping to the air. Zeolite is a binder that traps the ammonium in the manure, thereby lowering volatilization. Unpublished research from our group indicates the 3.5% dietary inclusion of EcoCaltm led to a 23% decrease in ammonia emission from laying-hen manure during the winter months (December to May) in the Midwest. This study involved two high-rise laying-hen houses, each containing approximately 250,000 hens. Hens in one house were fed a standard diet while hens in the other house were fed a diet containing 3.5% EcoCaltm.

Table 1 shows the ammonia decrease observed in various experiments conducted by our group. Emission rates are affected by many variables such as season, which may influence the actual reduction that is realized at a specific farm. Choice of dietary manipulation should be made by the egg producer based not only on anticipated ammonia reduction but also on ingredient cost, availability, and logistics of changing the diet.

Table 1. Comparison of diets

Item	Ammonia Decrease %	Inclusion Rate %	Diet cost[1] ¢/kg ($/2,000 lb)
Standard corn, soy, meat and bone meal diet	–	–	26.6 (241)
One percentage unit lower crude protein[2,3]	10	–	26.1 (237)
Corn distiller's dried grains with solubles (DDGS)[4]	41	10.0	25.5 (231)
Wheat middlings[4]	38	7.3	26.7 (242)
Soybean hulls[4]	27	4.8	27.6 (250)
EcoCal™,[5]	23	3.5	27.6 (250)

[1] Ingredient costs used were those reported for Midwest United States markets for April 2008 (see text). EcoCal™ cost from personal communication: E.C. Hale, III (April 15, 2008).

[2] In the study performed by Liang et al. (2005) and in the sample diet used for cost comparisons, DL-methionine, L-lysine, and L-threonine were added to meet the methionine + cystine, lysine, and theonine requirements, respectively, and soybean meal was added to meet the fourth-limiting amino acid requirement.

[3] Ammonia decrease was based on a one-year study by Liang et al. (2005) under commercial production involving 4 high-rise laying hen houses.

[4] Ammonia decrease was based on a 10-month study by Roberts et al. (2007) that involved 256 hens.

[5] Ammonia decrease was based on a 6-month study under commercial production involving 2 high-rise laying hen houses.

Applicability:

The research described herein focuses on lowering ammonia emission from laying hens using dietary manipulation. Some work has been done using these methods in pigs and the mechanisms should hold true for other types of poultry (i.e., broiler chickens and turkeys). However, these discussions are only directly relevant for laying hens.

Limitations:

Livestock producers should consult a qualified nutritionist prior to making changes in any diets to assure optimum nutritional status and animal performance.

Care should be taken when formulating reduced crude protein diets. The amino acid requirements of the animals must be precisely known for the specific production situation considered. Inclusion of dietary amino acids above the animals' requirements is costly and contributes to nitrogen excretion, thereby decreasing the overall effectiveness of the ammonia-lowering regimen. Furthermore, the digestible amino acid contents of all ingredients in the diet must be known, so that the diet can be balanced with amino acid contents closely resembling the requirements of the animal. If the animals' amino acid requirements are not precisely known or the amino acid contents of feed ingredients are overestimated, the diet may be deficient in one of more amino acids, which will decrease production and indirectly increase ammonia excretion. If the animal has an amino acid deficiency, it will excrete the nitrogen from all amino acids fed above the level of the deficient amino acid.

There are a few points to consider when including high-fiber feed ingredients in laying-hen diets. The nutrient content and digestibility of the "new" ingredient should be evaluated so the diet formulation can take full advantage of those nutrients. High-fiber ingredients tend to have a lower amino acid digestibility compared to corn and soybean meal, so diets should be formulated on a digestible amino acid basis. Furthermore, high-fiber ingredients usually have low energy content, which may make such ingredients unsuitable for nutrient-dense pullet or peaking diets. As with any feed ingredients, producers should secure a consistent, high-quality supply for optimum diet quality and animal production.

EcoCaltm is added at either 3.5 or 7.0% of the diet, replacing equal parts of calcium from calcium carbonate. The mixture of calcium sulfate and zeolite is adjusted according to the desired addition. The calcium in the product can be considered in the total diet formulation, lowering the inclusion of calcium carbonate (i.e., limestone). When feeding EcoCaltm, egg producers should be aware of a potential increase in hydrogen sulfide emission stemming from the sulfur in the calcium sulfate. While feeding 3.5% dietary EcoCaltm caused a 23.2% decrease in ammonia emission from laying hens, a 134% increase in hydrogen sulfide was observed (1.82 ± 0.07 mg/d per hen for control-fed hens and 4.38 ± 0.20 mg/d per hen for the EcoCaltm fed hens) over a 173-d experiment conducted by our research group (unpublished data). Hydrogen sulfide concentrations were maintained below 200 ppb or 0.2 ppm at the exhaust fans in the treatment house. Although significant increases in hydrogen sulfide concentrations and emissions were observed, the levels remain low and should not cause worker or hen health concerns or trigger reporting thresholds. For instance, the emergency planning and community right to know act (EPCRA) requires reporting of hydrogen sulfide releases greater than 45 kg (100 lb) per day. At the observed, elevated hydrogen sulfide emission rate of 4.38 mg/d per hen, it would take 10.3 million hens to emit 100 lb per day.

Cost:

To compare cost differences between mitigation strategies, example diets were formulated and costs calculated (Table 1). Ingredient costs published in Feedstuffs magazine April 14, 2008 for Chicago markets were used. The following ingredients' prices are not published by Feedstuffs and were set as listed: calcium carbonate 3.2¢/kg ($29/2,000 lb), l-lysine HCl $2.20/kg ($2,000/2,000 lb), dl-methionine $2.55/kg ($2,313/2,000 lb), l-threonine $2.82/kg ($2,560/2,000 lb), and EcoCaltm 16.5¢/kg ($150/2,000 lb). Ingredient nutrient values published by NRC (1994) were used for all ingredients except corn DDGS nutrient values (not including energy) taken from University of Minnesota (UMN, 2008) and soybean hulls and wheat middlings values published by Hy-Line (2006). A value of 2,805 kcal/kg (1,272 kcal/lb) was used for the metabolizable energy content of the corn DDGS (Dakota Gold, 2008). Calcium content of EcoCaltm was assumed to be 17.14%. Diets were formulated to contain 2,850 kcal/kg (1,293 kcal/lb) metabolizable energy. Total lysine was set at 0.80% of the diet and other amino acid inclusions were calculated using the ideal amino acid profile reported by Bregendahl et al. (2008). For all other nutrients, recommendations published by NRC (1994) were used.

Diets were formulated by including dl-methionine to meet the methionine + cystine requirement and adding soybean meal to meet the second-limiting amino acid requirement. Meat and bone meal was added to meet the requirement for available phosphorus. The reduced-protein diet was formulated by including dl-methionine, l-lysine, and l-threonine to meet the methionine + cystine, lysine, and threonine requirements, respectively, and including soybean meal to meet the fourth-limiting amino acid requirement. EcoCaltm, corn DDGS, soybean hulls, and wheat middlings inclusion rates were set at the inclusion used in the respective experiment (3.5%, 10%, 4.8%, and 7.3%, respectively). All nutrient contributions from each ingredient were considered in the formulations. For the example diets prepared, the cost of the standard diet was $241/2,000 lb. The corn DDGS diet was $10/2,000 lb less expensive while the reduced protein diet was $4/2,000 lb less expensive compared to the standard diet. The wheat middlings diet was $1/2,000 lb more expensive and the EcoCaltm and soybean hulls diets were each $9/2,000 lb more expensive compared to the standard diet.

Implementation:

Producers should use care when reformulating diets to assure that all nutrient requirements of the hens are met. Feed ingredients should be sourced from a reputable company with high-quality, consistent products and should be analyzed to determine nutrient content of the ingredients prior to diet formulation to ensure optimal performance of the hens. Ingredient costs may vary greatly for different egg producers based on the proximity to the supplier and private contracting (including volume discounts)

Technology Summary:

Dietary manipulations can lower ammonia emission from laying-hen manure. Options discussed in this report include:

- Reduced crude protein diets;
- Including high-fiber ingredients (e.g., corn DDGS, wheat middlings, or soybean hulls); or
- Including EcoCal™.

Each different dietary manipulation technique offers positive and negative aspects that will fit differently into individual production systems. Producers should work closely with a qualified nutritionist to decide which diet would be best suited for their operation and to implement the changes such that all diets are nutritionally balanced and optimal egg production is achieved. Cost comparisons should be evaluated as the cost of the total diet and calculated for each individual production situation.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
Iowa State University College of Agriculture and Life Sciences
Conference Proceedings
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Feeding a Combination of Acidogenic Materials and Cation Exchangers Reduces Manure Ammonia Emissions and Improves Laying Hen Performance

E. C. Hale III
Earth Net, LLC

Species: Poultry
Use Area: Animal Housing
Technology Category: Diet Modification
Air Mitigated Pollutants: Ammonia

Description:

Poultry manure ammonia emissions can be significantly reduced by dietary manipulation. Feeding suitable levels of acidogenic materials and indigestible cation exchangers to laying hens in a production environment resulted in average manure ammonia emission reductions of up to 68%.

Improvements in the production environment reduce bird stress, resulting in improved performance and reduced production costs.

Mitigation Mechanism:

The mitigation mechanism is a two-step process. Ammonia (NH3) is a neutrally charged molecule that protonates to form the cationic molecule ammonium (NH4+) when subjected to acidic pH levels.

As excreted, poultry manure exhibits a basic pH, so substantially all of the ammonia produced by enzymatic degradation of uric acid exists as ammonia. When acidogenic materials are introduced into the diet, manure pH is reduced. When fed in sufficient amounts, manure pH can be reduced so that substantially all the ammonia is protonated, forming ammonium. It would be ordinarily expected that the cationic ammonium would react with the acidic anion causing the pH reduction, but this reaction tends to be inefficient.

When an indigestible cation exchanger with a strong preference for binding ammonium is fed along with sufficient levels of an acidogen to reduce manure pH to 7 SU or below, the ammonium strongly binds to the cation exchanger, and is effectively sequestered in the manure.

Applicability:

This feed program is suitable for use by egg producers who wish to improve bird health through reducing levels of ammonia in the production environment. The feed program is suitable for use in high-rise, belt-battery, aviary, and free-range housing environments.

Limitations:

In general, overfeeding acidogens can affect the acid-base balance of the bird to a point where performance is adversely affected. Two acidogens have been evaluated as part of the combined feed system--gypsum and sodium bisulfate.

For laying hens, the highest ammonia emission reductions were noted when gypsum supplied approximately 35% of the calcium in the diet. Using gypsum as the source for more than about 60% of dietary calcium resulted in slightly reduced overall production and thinning eggshells. The adverse effects increase as gypsum levels increase beyond the point where they supply 60% of dietary calcium. At levels where gypsum supplied 72% of dietary calcium, marked decreases in egg numbers and shell quality were noted.

Sodium bisulfate is also an effective acidogen for laying hens, and can be used to reduce ammonia emission rates for broilers, as well. Sodium bisulfate is a source of dietary sodium, and can be used as a replacement for other sodium sources in the diet. Sodium bisulfate should comprise between 0.5% and 0.75% of the feed for either layers or broilers, with a 0.75% inclusion rate being the more effective of the two at reducing manure pH. At those levels, sodium bisulfate does not supply sufficient sodium or chloride to meet the dietary needs of the bird. A combination of sodium chloride and potassium chloride should be used with sodium bisulfate to meet dietary sodium and chloride levels. Sodium bisulfate should not be fed at levels which would cause overfeeding of sodium.

Two indigestible cation exchangers have been evaluated, zeolite and humate. Both are similarly effective at sequestering ammonium cations, and can be used in concert with gypsum or sodium bisulfate.

Zeolite and humates generally exhibit either neutral or slight basic slurry pH levels, and have significant buffering capacities. In general, as long as the buffering capacity of the cation exchanger does not too significantly affect the pH reduction caused by the acidogen, the higher the inclusion rate of the cation exchanger for any given level of acidogen fed, the higher the ammonia emission reduction noted.

With regard to feeding zeolites and humates at levels well in excess of the amount needed for optimal ammonia emission reductions, no adverse effects have been noted.

Cost:

If there is available bin space at a feed mill, no initial capital expenditures are needed to implement the diet. The gypsum/zeolite version is available in a pre-mixed form and can be delivered in bulk, or the materials can also be sourced on the open market and blended directly at the feed mill as needed.

Sodium bisulfate/zeolite or sodium bisulfate/humate versions are not currently available in a pre-mix version, but each component comprises a small enough percentage of the feed that they can be added to the ration via an existing micro-bin system.

For laying hens, per-ton amended feed costs are increased compared to per-ton standard feed costs. However, increased overall production, improvements in saleable egg numbers, improved feed conversion ratios, and reductions in mortality more than offset the increased feed cost.

Implementation:

A diet comprising 5.75% gypsum and 1.25% zeolite was fed to 125,000 hens in a high rise house. An additional 125,000 hens of the same age acted as control. Temperature set-points were the same, airflow controls, and fan stage operation was set the same to cause both houses to be under the same operating conditions. Both houses were constructed alike, and had the same number and type of fans installed in analogous locations. Manure amounts in the storage pit were the same. Hen diets were nutritionally equivalent, despite differences in formulation.

Insuring that airflow, temperature, etc., were the same between both houses enabled those factors to be removed from consideration when determining emission rate differences, so that any differences in ambient ammonia levels corresponded with differences in emission rates.

In order to determine the average ambient ammonia concentration in exhaust air, 10 analogous fans that were always in operation were identified in each house. An ammonia meter (Bacou-Dalloz ToxiPro) was placed in the airflow of each fan, allowed to equilibrate, and the reading recorded. This was done in each of the two houses, and an average ammonia level was calculated for each house. Then, the two values were compared to determine the difference in ammonia levels between the two houses.

Prior to collecting data, the test house was fed the amended diet for a period of one week, to allow the hens to acclimatize to the new diet. Data was collected every other day for a period of a month after the acclimatization period. The average reduction over the trial period was 68%. Graph 1 illustrates the results of the trial.

Over a 14-week period, 375,000 laying hens of varying ages were fed a diet comprising 2.5% gypsum and 1.0% zeolite. An additional 375,000 hens of varying ages were fed industry standard rations as a control. Production parameters were monitored for both groups. Prior to implementing the diet, production data from both groups was compared to determine any innate differences between the two groups. No statistically significant differences in any of the monitored parameters were noted. After implementation, hens fed the test diet exhibited statistically significant improvements in production. The parameters monitored and any increases or decreases in those parameters exhibited by the hens fed the test diet are shown in Table 1.

For 12 weeks of the 14 week period, relative ambient ammonia level data was collected, using the same controls and methods previously outlined. As before, controlling temperature and fan operation to insure consistant airflow between the houses allowed the difference between average ambient ammonia levels to adequately represent differences in emission rates. Over the 12 week period, the average reduction was 44%. The results are reported in Graph 2.

Graph 1

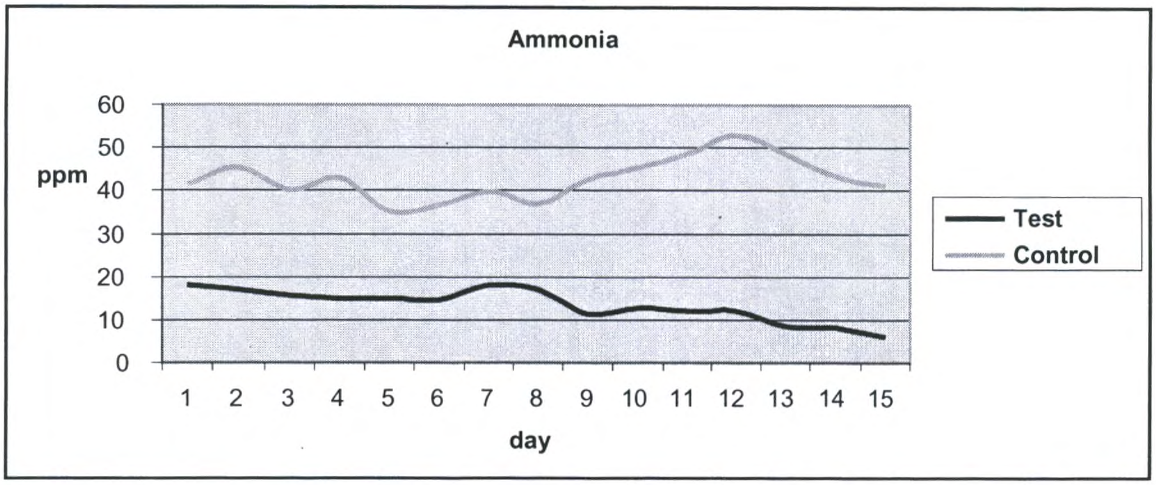
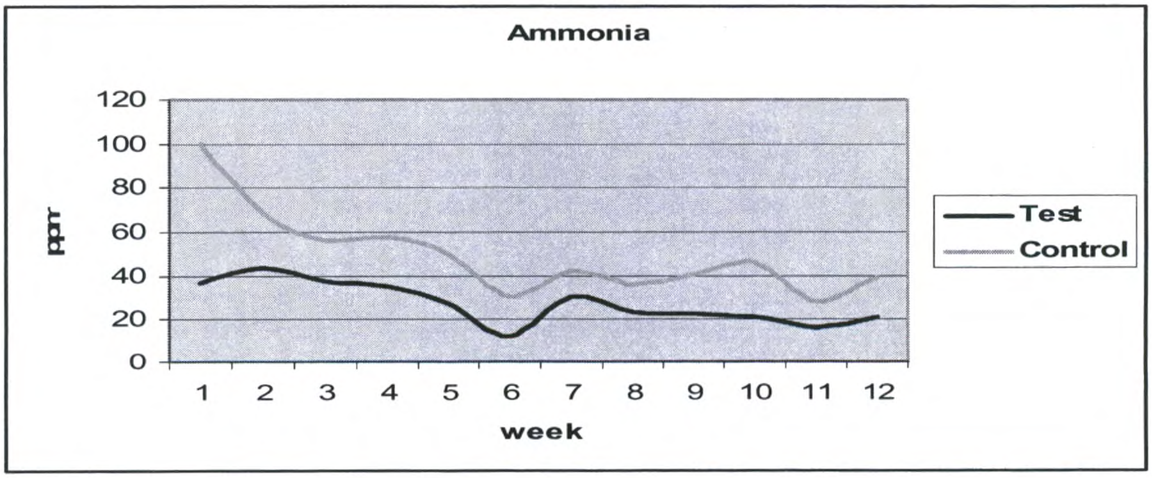


Table 1

14 Week Implementation Cost Test, Production Scale (~750,000 hens)

	Difference, %
Total Production, dozen eggs/week	+5.92
Grade A, Lg+, dozen eggs/week	+5.28
Grade A Total, dozen eggs/week	+3.50
Mortality, hens/week	-21.51
Lbs Feed to produce a dozen eggs/week	-1.95
Feed Cost, per ton	+2.23
Undergrade, dozen eggs/week	-0.40
Total Feed Consumed/week	+3.49
Cost to Produce a Dozen Eggs	-3.24

Graph 2



Technology Summary:

Feeding laying hens a combination of acidogenic materials and indigestible cation exchangers reduces manure ammonia emissions by effectively sequestering ammonium in the manure. Reductions of between 44% and 68% were noted, depending on the amounts of acidogens and cation exchangers fed.

Initial feed costs were elevated, but improvements in performance translated into a reduction of per-dozen production costs.

Additional Resources:

Additional information regarding feeding acidogens, cation exchangers, and combinations of the two is available on the internet through a variety of sites.

Acknowledgments:

Thanks to Dr. Albert Heber for his assistance in designing the strategy used to estimate relative differences in emission rates between poultry houses using simple equipment that can be implemented at farm level.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
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Manure Ammonia Emission Reductions Achieved by Feeding DDGS to Laying Hens Housed in a Production Environment

E. C. Hale III
Earth Net, LLC

Species:	Poultry
Use Area:	Animal Housing
Technology Category:	Diet Modification
Air Mitigated Pollutants:	Ammonia

Description:

Feeding a diet comprising 10% Dried Distillers Grains plus Solubles (DDGS) has been found to reduce manure ammonia emissions by up to 50% in a laboratory environment (Roberts, et al, 2006).

In order to determine the effects of a diet comprising 10% DDGS on manure ammonia emissions in a production environment, 80 laying hens were fed a 10% DDGS died for a 6 week period. An additional 80 hens were fed a standard ration as a control. Both diets were nutritionally equivalent.

The effect of feeding a 10% DDGS diet on production was not determined in this study.

Mitigation Mechanism:

It has been posited that increased levels of fermentable fiber in the diet cause increased microbial production of volatile fatty acids, which reduces manure pH (Roberts, et al, 2006). The reduction in manure pH protonates ammonia (NH3) produced during uric acid breakdown, forming ammonium (NH4+). Ammonium is significantly less volatile than ammonia and remains in the manure, thus the observed reduction in emission rate.

Applicability:

Feeding diets containing DDGS is suitable for use in laying hens, kept in any type of housing system.

Limitations:

Virginiamycin is commonly used in the production of ethanol, and is expected to be present in DDGS at levels between 0.2 and 0.5 parts-per-million (ppm). Heat is used to dry DDGS, and Virginiamycin is reported as stable at 90 degrees Celsius. The effect of heat at varying temperatures above 90 degrees Celsius on Virginiamycin stability has not been sufficiently explored to conclusively state that all the Virginiamycin in DDGS is destroyed during the drying process.

The presence of detectable levels of Virginiamycin in dried DDGS has been reported (Hale 2008).

The US Food and Drug Administration (USFDA) prohibit feeding laying hens materials containing detectable levels of Virginiamycin. Because DDGS is produced in a batch process, each batch of DDGS considered for inclusion in a laying hen diet should be tested to insure that Virginiamycin is not present.

Excessive heat used to dry DDGS reduces metabolizable energy (ME), amino acid content, and amino acid digestibility (AAD) in DDGS (Batal, et al, 2006).

The lack of uniformity in DDGS processing from supplier to supplier and from batch to batch causes significant variability in ME, AAD, and amino acid content (Batal, et al, 2006), making feed formulation more difficult.

Care must be taken to determine whether DDGS being incorporated into feed contains mycotoxins. A recent study indicates that essentially all DDGS contains some level of mycotoxins, and usually more than one type of mycotoxin is present (Rodrigues, 2007).

Cost:

When laying hens were fed a diet containing 10% DDGS, feed consumption increased and egg production remained unchanged as compared to control (Roberts, et al, 2006). A comparison of the cost of amended feed versus standard feed was not given.

The economics of feeding DDGS as a method of controlling ammonia emissions has not been fully explored at this time.

Implementation:

In order to determine the effect of a 10% DDGS diet on manure ammonia in hens housed in a production environment, 80 hens were fed a diet comprising 10% DDGS, and an additional 80 hens acted as a control. The amended and control diets were formulated to be nutritionally equivalent. The diets were also formulated to be consistent with standard dietary requirements for the type and age of hen used in the study.

The hens were fed for a 1-week acclimatization period prior to removing manure for emission testing. Fresh manure was then collected on a weekly basis, and analyzed to determine the total amount of ammonia emitted over a 4-day period. The bulk of manure ammonia emissions affected by inclusion of DDGS in the diet are related to uric acid conversion to ammonia. The conversion begins immediately upon excretion, and is essentially complete within 4 days post-excretion.

The hens were housed in standard battery cages, 5 hens per cage, 20 hens per unit, and a total of 4 units were fed each diet (control, amended).

Manure samples were obtained by removing all manure under the caged hens. Three hours later, all manure was removed from under each unit, placed in a sealed glass jar, and transported to the laboratory. Manure samples from each unit were homogenized, and a 25-gram aliquot removed. Each aliquot was placed in a flask and air passed across it. The ammonia-laden air was bubbled through a 0.04N sulfuric acid solution to trap the ammonia. Every 24 hours for a period of 4 days, the solution was exchanged for fresh solution. At the end of the test, each solution was assayed to determine how much ammonia had been emitted over a given 24-hour period. The data was used to construct emission curves for each unit of hens. Average total emissions for each group (control, amended) was calculated and compared to determine what effect, if any the amended diet had on ammonia emissions.

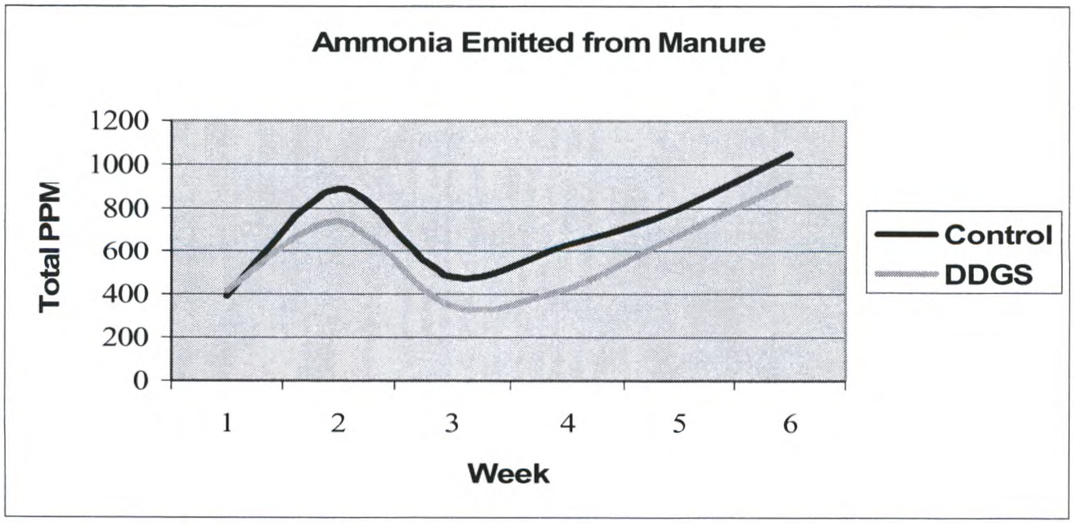
The trial was concluded after 6 weeks. Total average manure ammonia emissions and percent difference values for each group is shown on a per-week basis in Table 1 and Graph 1.

Table 1

Average total manure ammonia emissions over a 4-day period, data reported in ppm

	Control	**10% DDGS**	**% Difference**
Week 1	392.85	417.7	6.3
Week 2	887.7	741.0	-16.5
Week 3	475.6	340.7	-28.8
Week 4	630.9	421.1	-33.3
Week 5	799.1	681.0	-14.8
Week 6	1049.9	922.1	-12.2
Average	**706.5**	**587.25**	**-16.9**

Graph 1



Technology Summary:

A diet containing 10% DDGS can be fed to reduce manure ammonia emissions on average, with no apparent loss in productivity. The level of reduction appears variable.

When feeding DDGS to laying hens, care must be taken to insure compliance with FDA regulations regarding the presence of Virginiamycin.

When formulating a diet containing DDGS, care must be taken to insure that the variability of ME or AAD in DDGS from different sources and even different batches from a single source is considered.

Additional Resources:

Additional resources can be found on the internet.

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Effects of EcoCal^{TM} on Ammonia Emission from a High-Rise Layer House

T. Lim[1], A. Heber[1], E. Hale III[2], J. Ni[1], and L. Zhao[3]
Purdue University[1], Rose Acre Farms[2], Ohio State University[3]

Species:	Poultry (Layer)
Use Area:	Animal Housing
Technology Category:	Diet Modification
Air Mitigated Pollutants:	Ammonia

Description:

Ammonia (NH_3) is released in significant amounts from livestock and poultry facilities, especially from high-rise layer houses. Abatement technologies such as diet manipulation, manure amendment, improved manure drying, and frequent manure removal can be applied to high-rise layer houses to reduce NH_3 emission. However, very few studies have been conducted to quantify the effectiveness of these technologies, and report associated costs. The NH_3 emission rate of a modern manure belt house is less than one-third of the NH_3 emissions from high-rise houses (Sun et al., 2005). Emission studies conducted by Liang et al. (2005) concluded that manure belt houses emit significantly less NH_3 than high-rise houses (Liang et al., 2005). While most new construction are now manure belt, many of the existing high-rise layer houses would benefit from applicable abatement technologies, such as feed additives or manure amendments, to reduce NH_3 emission from the large quantity of manure stored in the first floors of these houses. A proprietary, patent-pending feed additive, EcoCal^{TM}, was tested for its effectiveness in reducing NH_3 emission from a high-rise layer house in Ohio.

Mitigation Mechanism:

Techniques that reduce manure pH are effective in reducing emission, since NH_3 volatilization from manure increases at higher pH. This mitigation approach can be either pre-excretion, or post-excretion. The dietary manipulation of manure pH is achieved by adding acidogenic phosphorus and/or calcium salts to the feed to decrease manure pH.

EcoCal is a combination of an acidogen (gypsum) and an indigestible cation exchanger (clinoptilolite zeolite). EcoCal's mitigation mechanism is a two-step process. With the proper amount of acidogenic materials included in the diet, manure pH is reduced so that more ammonium (NH_4+) is formed. This results in more nitrogen sequestered in the manure rather than released as NH_3.

Applicability:

Since both gypsum and zeolite are naturally occurring minerals, and are shown to improve feed conversion, EcoCal can be used for feeding laying hens housed in typical commercial egg production facilities. EcoCal is also suitable for use in organic egg production.

Limitations:

Diets with more than 60% of dietary calcium supplied by EcoCal should be avoided since overfeeding gypsum can result in thinning egg shells and lower production. However, diets containing 7% EcoCal are well below that threshold, and at that level, the gypsum in EcoCal supplies approximately 35% of the calcium needed in a typical layer diet.

The zeolite component in EcoCal is safe even when fed at levels well in excess of the amount needed for optimal ammonia emission reductions. No adverse effects on health or production have been noted.

Cost:

The gross cost of adding EcoCal was about 2.4 cents per hen per month or $28,700/yr per 100,000 hens. The effects of EcoCal on egg production were not evaluated in this test, but any increases in egg production would offset the extra cost.

Implementation:

A field evaluation of EcoCal was conducted at two 169,000-hen, mechanically –ventilated, high-rise layer houses in Ohio. The test was conducted at the site of a six-month particulate impaction system test that started on August 1, 2004 (Lim et al., 2007). Data presented in this paper was collected from October 20 to January 26, which includes about six weeks of data before EcoCal treatment was introduced in house 2 on December 3. The W-36 laying hens in house 2 were fed a diet consisting of 7% EcoCal to determine its effects on NH_3 emission rates. The untreated house 1 housed W-98 laying hens, which were fed an industry standard diet. Nutritional content was adjusted to the genetic, age, and production status of the hens in both of the houses.

Ammonia concentrations (ppm) were measured at the house exhaust fans and in incoming air using well-maintained and calibrated online analyzers. Other measured variables included house temperature, relative humidity, static pressure, and fan operation (Lim et al., 2007). After EcoCal was introduced in house 2, the mean daily exhaust concentrations became consistently less than house 1, Figure 1. After 10 days following the introduction of EcoCal, the daily mean exhaust concentration at the treated house was always less than the untreated house. Prior to introducing EcoCal, the mean exhaust concentrations of house 2 was very similar to house 1 from October 20 to November 16, but was much greater than house 1 during the two weeks prior to introducing EcoCal, Figure 1.

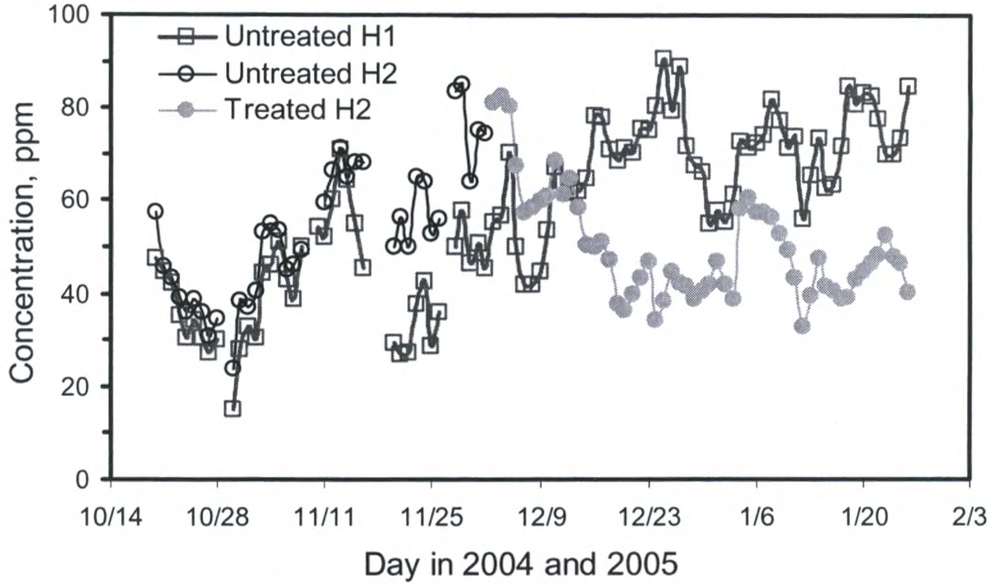

Figure 1. Daily mean NH_3 concentrations of untreated house 1, and treated house 2.

Similar to the NH_3 concentrations, the emission rates of house 2 were higher than house 1 prior to the introduction of EcoCal on December 3, Figure 2. The overall average NH_3 emission rate of the untreated house 2 was 25% higher than house 1 during the six weeks prior to December 3. Since the NH_3 emission rate of untreated house 2 was higher than the untreated house 1 in the six weeks prior to EcoCal implementation, the overall emission reduction of 51% due to EcoCal applications may be an underestimate. However, given the fact that there was only one treated house, and lack of test replication, the house difference before the treatment was not used to adjust the reductions in the subsequent test. The overall emission reductions after December 14, assuming the effects of EcoCal has stabilized in about 10 days, averaged 51%, and ranged from 18% to 69%.

Some important differences existed between the two houses. For example, the laying hens varied widely in age, genetics, and dietary crude protein requirements. The birds in houses 1 and 2 were 111 and 34 weeks old on December 1 and the mean weights were different. These factors had all contributed to the uncertainties of the emission reduction assessment. It is thus important to compare the emission rates based on per animal unit basis, where one animal unit equals 500 Kg of animal weight. The mean NH_3 emission rates were 327 g/d-AU for the untreated house 1 and 356 g/d-AU for the untreated house 2 during the six weeks prior to December 3, Table 2. The mean NH_3 emission differences between the houses were -25%, -12%, and 51% for the three test periods, Table 2.

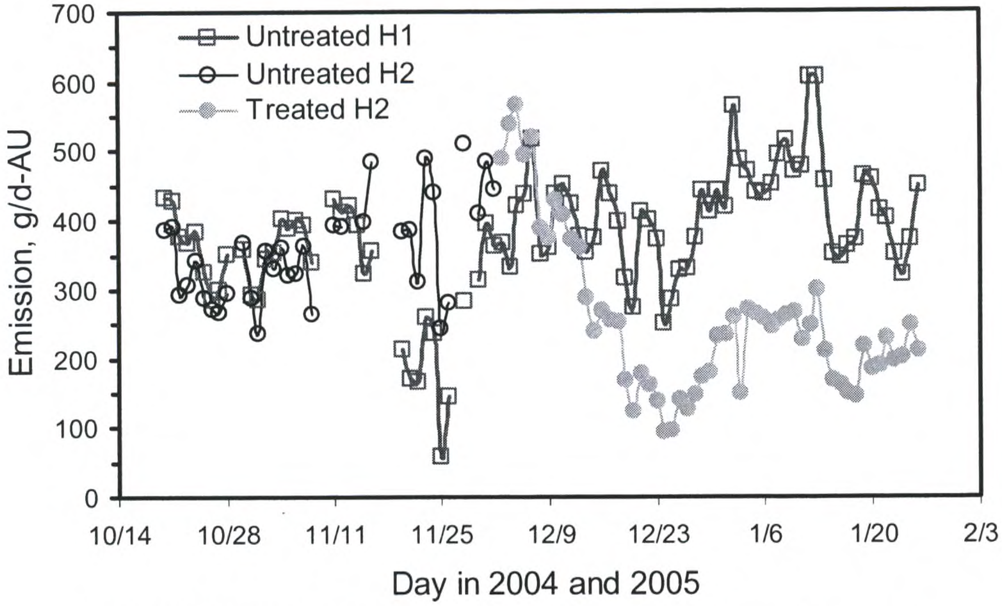

Figure 2. Daily mean NH_3 emission rates of untreated house 1 and treated house 2

Table 2. Emission rates and differences between treated and untreated houses.

Date	Treatment status	Emission rate, g/d-AU		Difference, %
		House 1	House 2	
10/20-12/2	None	326.6	356.0	-25.3
12/3-12/13	Treatment (transition)	407.2	449.0	-11.7
12/14-1/26	Treatment (equilibrium)	414.5	205.0	50.6

Besides the pre-existing higher emission rates in the treated house prior to treatment, another differences occurred later as a flood in the house 2 manure pit occurred on January 16. The flood in the house 2 pit was caused by a broken water supply pipe. The wetter manure in the treatment house had probably emitted more NH_3, thus working against the treated house in the comparison. Nevertheless, the NH_3 emission from the treated house remained consistently less than the emissions from the untreated house, and was 51% lower overall. Considering the emission differences between the two houses prior to the test, the overall reduction in NH_3 emission rates due to EcoCal was about 63%.

Technology Summary:

Continuous emission measurements at two mechanically-ventilated, high-rise layer houses were conducted to study the effects of Ecocal, a feed amendment, on reducing NH_3 emissions. Data presented in this paper was collected from October 20 to January 26. The hens in house 2 were fed a diet amended by EcoCal, while the standard diet was used in house 1, which served as the untreated house for comparison. EcoCal utilizes gypsum (acidogen) and zeolite (indigestible cation exchanger) to decrease manure pH and, in turn, reduce NH_3 emissions. Feeding a diet with 7% EcoCal significantly reduces ammonia emissions by effectively sequestering ammonium in the manure. An average reduction of 51% based on barn-to-barn differences was observed for one month after the emission rate stabilized following the introduction of EcoCal in house 2.

The application of the EcoCal was expected to reduce NH3 emissions greater than 51%, but the test was compromised hindered by several unexpected incidents such as flood and disruption of feed delivery. The initial feed costs were increased by or $28,700/yr per 100,000 hens when EcoCal was added to the diet, but improvements to the production environment caused by EcoCal may improve productivity, which could offset the additional feed cost.

Acknowledgments:

The Purdue Agricultural Research Programs is acknowledged for their support.

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As published in the proceedings of:
MITIGATING AIR EMISSIONS FROM ANIMAL FEEDING OPERATIONS CONFERENCE
Iowa State University Extension
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Iowa Pork Industry Center
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Animal Housing-Biofilters and Scrubbers

Practical Partial Biofiltration of Swine Exhaust Ventilation Air

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Iowa State University[1], University of Minnesota[2], South Dakota State University[3]

Species: Swine
Use Area: Animal Housing
Technology Category: Biofilter
Air Mitigated Pollutants: Ammonia (NH_3), Odor

Description:

The mitigation technique discussed is to utilize biofiltration for a portion of swine barn ventilation air. The portion mitigated is that portion of air emitted into stable atmospheres. Stable atmospheres have poor vertical mixing potential and therefore gases and odors emitted tend to remain close to the earth's surface and can therefore be sensed at longer distances downwind. It is impractical to mitigate all of the exhaust ventilation air required in swine housing. Techniques are needed that apply odor and gas mitigation to a portion of the ventilation air stream, when receptors might experience an odor event. Additionally, many barns incorporate combinations of fans and curtains (i.e. hybrid ventilated) to supply required ventilation air. Any mitigation strategy applied to barn ventilation air must be able to accommodate these hybrid ventilation systems as well.

Ventilation air exhausted during the heat of summer days is exhausted into an atmosphere that is, for the vast majority of times, very unstable providing excellent and natural mixing potential near the building source. In more stable atmospheres, typically present during the evening hours, biofiltration of a critical minimum amount of ventilation air (i.e. partial biofiltration) would reduce ammonia and odor emissions during those times when the potential for odor plumes to travel long distances is greatest. The overall effect would be a more attractive biofiltration strategy that maximizes ammonia and odor reduction potential when most needed.

A strategy for providing partial biofiltration of a critical minimum amount of ventilation air for hybrid ventilated swine finishing facilities was developed and tested. The biofiltered critical minimum ventilation air (CMVR) was set at 81 m^3/h^-pig (48 ft^3/min-pig) with the intention of providing enough fan ventilation in a hybrid ventilated swine finishing facility to suppress curtain movement during stable atmospheres. Two side-by-side 300-head hybrid ventilated deep-pit swine finishing rooms were used for this research, one room as the control (CTL) with the other treatment (TRT). The TRT room was fitted with a wood-chip based biofilter for scrubbing the CMVR. In terms of total room emissions, the TRT room had an average odor emission 37% less and an average ammonia emission 58% less than the CTL room.

Mitigation Mechanism:

Past research on swine housing ventilation rate characteristics indicates that significant rate changes occur over most summer days in order to maintain an acceptable internal climate (Hoff et al, 2004). The maximum ventilation rates experienced during the heat of the day are exhausted to an atmosphere that is, for the most part, very unstable resulting in significant vertical mixing and dilution near the source. Likewise, during more stable and cooler summer evening hours, a lesser amount of ventilation air is required to maintain an acceptable internal climate. This change in ventilation requirements, as a function of atmospheric stability, can be used to enhance the usefulness of odor and gas mitigation for barn ventilation air.

Partial biofiltration, to be effective, must be applied to that portion of the ventilation air that is required for the predominant periods associated with hot weather evenings. This "critical minimum" amount of ventilation air mitigated would treat exhausted air when the potential for off-site gas and odor transport is greatest. This strategy will serve two useful purposes; first, the amount of air required for biofiltration will be significantly less than the maximum barn capacity, and second, the end result will be a reduction in source emissions of key pollutants that are currently being reviewed by the USEPA (2005).

This research defines a critical minimum ventilation rate (CMVR) that encompasses, for the majority of time, ventilation air that is delivered during the more stable evening hot-weather hours. Figure 1 is an example of a central Iowa deep-pit swine finisher and the ventilation rate changes over a six-day period (USDA, 2001). This six-day sample (Aug 14-19, 2003) shows that the ventilation rate was near maximum (140,000 m^3/h = 146 m^3/h-pig = 86 ft^3/min-pig) during the hot periods of mid-day as would be expected. However, during early evening, evening, and early morning hours the ventilation rate required reduced to a rate of about 50,000 m^3/h (= 52 m^3/h-pig = 31 ft^3/min-pig). It is the ventilation air that predominates during hot-weather evening hours that would be considered the critical minimum, leaving the remaining exhaust air to disperse and dilute naturally with the corresponding unstable day-time atmospheres.

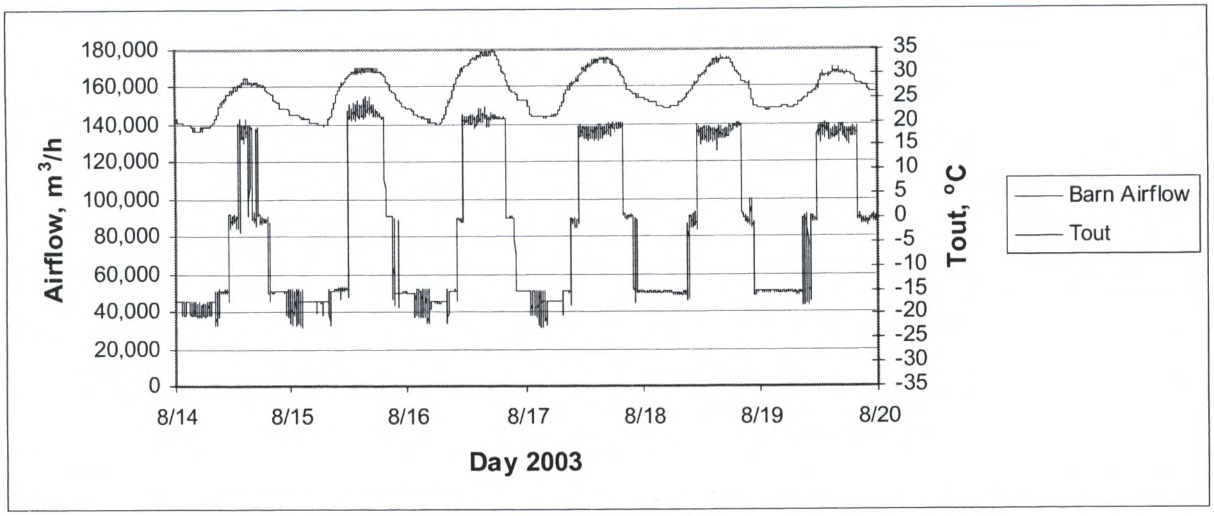

Figure 1. Building airflow changes with summer outside temperature.

The goal of this research was to test a partial biofiltration strategy that could be implemented to mitigate a "critical minimum" amount of ventilation air from hybrid ventilated deep-pit swine finishers. Mitigation performance and operating costs are presented in this paper. Highlights of this research are discussed in this paper. A more detailed description can be found in Hoff et al. (2008).

Applicability:

The strategy of partial biofiltration presented in this paper was developed for hybrid ventilated swine finishing facilities. The concept of partial mitigation, beyond biofiltration, can be implemented to other gas and odor mitigation technologies involving animal housing ventilation air. Partial treatment of ventilation air is in general an "impact-based" technology where mitigation is applied to exhausted air that has the potential for impacting neighboring residences.

Limitations:

Treatment of exhaust ventilation air from animal housing must not negatively affect animal performance with ventilation rate restrictions. It is important that fan capacity be sized appropriately to accommodate biofilter requirements while maintaining the integrity of the ventilation system required for the housed animals. The project presented here investigated the use of biofilters on hybrid-ventilated deep-pit swine finishing facilities. Implementation of partial biofiltration on alternative ventilation methods (ie. tunnel ventilated) was not conducted with this research.

Proper performance of biofilters requires an ample water supply to keep the biofilter media in the 50-60% range to be as effective as possible (Nicolai et al., 2006; Chen et al., 2008). In addition, one often over-looked situation that can exist in deep-pit swine finishing facilities is the fact that as manure level rises, there is a tendency for pit-fan intake blockage due to physical constraints between the slatted floor level and support beams required for the flooring. It is not uncommon to have pit fan intakes completely blocked with a full or near-full pit. In this situation, any mitigation strategy applied to pit fans is rendered useless.

Cost:

The biofilter application presented in this research required $4,959 for biofilter supplies and equipment including four new biofilter fans (table 1). The biofilter construction required approximately 120 hours of labor and at $15/hour equates to $1,800. In total, with supplies, equipment, and labor, the construction costs equaled $6,759 or $22.53/pig space. The biofilter fan operating costs averaged $0.0084/day-space to operate (June-October 2006 data used) compared to the control barn of $0.0034/day-space. This extra fan cost, spread over the pigs produced in one year, equates to an additional $0.42/pig-produced in biofilter fan operational costs.

Table 1. Biofilter construction costs.

Item	$/Unit	Unit	Units/ft^2	$/ft^2	Total*	$/pig-space	Life, yrs	Pigs/Life	$/pig
Concrete block	$0.94	each block	0.50	$0.47	$445	$1.48	30	22,500	$0.02
Support bars	$0.33	ft (3/4 inch diameter)	1.00	$0.33	$313	$1.04	15	11,250	$0.03
Hog panel	$0.38	ft^2	1.00	$0.38	$355	$1.18	15	11,250	$0.03
Fiberglass mesh	$0.67	ft^2	1.00	$0.67	$634	$2.11	10	7,500	$0.08
Replacement fans	$1,800	15,000 ft^3/min	1.00	$2.00	$1,894	$6.31	15	11,250	$0.17
Plywood border/plenum	$20.00	4 ft x 8 ft sheet	0.01	$0.20	$189	$0.63	7	5,250	$0.04
Wood chips	$1.43	ft^3	0.83	$1.19	$1,129	$3.76	3	2,250	$0.50
				Total less labor	$4,959	**$16.53**			**$0.87**
				Total less fans and labor	$3,065	**$10.22**			**$0.70**

* for the 947 ft^2 biofilter constructed.

Implementation:

This research was conducted at a cooperator's swine production site located in central Iowa. The facility used was a 600-head hybrid ventilated deep-pit swine finisher consisting of two 300-head rooms separated by a solid wall. Both rooms used a 2.4 m (8 ft) deep manure holding tank located below the fully-slatted flooring. The wall separating the two rooms also separated the manure holding tanks with the exception of equalizing channels at the bottom of the separating wall. One 300-head room was designated as the control (CTL) with the other used as the treatment (TRT). Both rooms were identical before the start of this experiment. Each room was ventilated with two 61 cm (24 in) diameter pit fans located on the north side of each room, placed over pump-out locations.

Curtains on both sides of each room were used to accommodate warm-to-hot weather ventilation requirements. These curtains, located on the north and south sides of each room, were controlled together by room but independent between rooms. The CTL and TRT configuration with the biofilter applied to the TRT room is shown in figure 2.

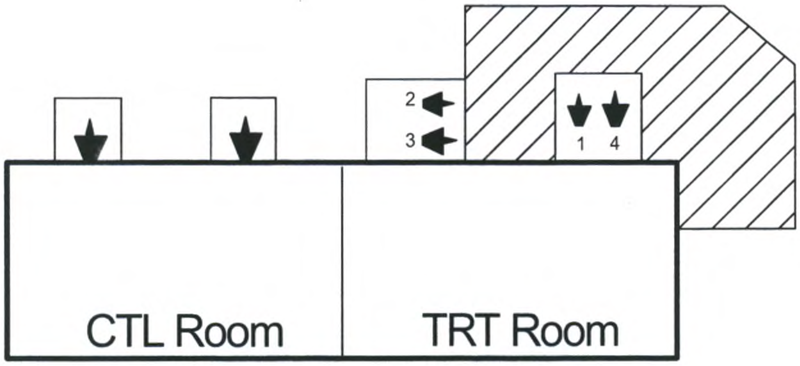

Figure 2. Biofilter layout with gas sampling locations.

The two original TRT room variable speed pit fans were replaced with four single-speed fans, controlled in four stages (table 2). Each of the four fans was progressively activated with each stage. At the final stage 4 condition, and assuming an operating static pressure of 75 Pa (0.30 in water column), results in an estimated maximum volumetric rate through the biofilter of 24,395 m^3/h (14,347 ft^3/min).

Table 2. Biofilter fan specifications and staging. All fans from Multifan, Inc.

Fan ID*	Model	Diameter, cm	Operating Static Pressure, Pa		
			0.0	12.5	75.0
1	4E30Q	30	2,380	2,295	1,615
2	4E40Q	41	5,270	5,015	3,400
3	6E63Q	61	12,240	11,730	9,690
4	6E63Q	61	12,240	11,730	9,690

*see figure 2

The biofilter design guidelines provided by Nicolai and Janni (1999), Janni et al. (2001), and Nicolai et al. (2002) were used for this research project. The target residence time for biofiltered air was 4 sec. At stage 4 with an estimated 24,395 m^3/h (14,347 ft^3/min) delivery rate, the biofilter volume required to achieve a 4 sec retention time was 27 m^3 (953 ft^3). The desired biofilter depth was established at 25 cm (10 in) resulting in a required biofilter surface area of