Sponsors

University of Minnesota
College of Veterinary Medicine

College of Food, Agricultural and Natural Resource Sciences

Extension Service

Swine Center

Thank you to **IDEXX Laboratories** for their financial support to reproduce the conference proceeding book.

Production Assistant
Janice Storebo

Formatting
Tina Smith

CD-ROM
David Brown

Logo Design
Ruth Cronje, and Jan Swanson;
based on the original design by Dr. Robert Dunlop

Air quality issues and perspective

Larry D. Jacobson, PhD, PE
Professor and Extension Agricultural Engineer, University of Minnesota, St. Paul, Minnesota

Introduction

Locating new animal production sites as well as managing existing facilities in the United States has become increasingly difficult for livestock and poultry producers due to a variety of environmental, labor, and financial issues including water quality concerns, labor shortages, market prices, and available capitol. However, maybe the single largest factor inhibiting the growth and operation of many US animal production farms is the outdoor air quality concerns of residents near the proposed or expanding livestock and poultry operations. Such concerns often include the effects of nuisance odours on people's quality of life and the effects that the odours and manure gases may have on human health and the environment.

Consolidation of the nation's animal production industries started in the 1950's with poultry and has progressed through beef, pork, and finally with the dairy industry. This consolidation has led to significant changes in the size of most production operations, resulting in a factor of ten increases or more in the number of animals on farms. An example can be seen on swine farrowing operations. In the early 1970's a Midwestern US farm with 200 sows was considered large, now a new farrowing operation with fewer than 2000 sows is rare. This transition to intensive rearing of animals has been overwhelmingly positive for the livestock and poultry industry: animal mortality rates have been reduced, feed efficiencies have improved, and productivity has increased. However, new problems have arisen for the industry, one of which is the impact of animal based agriculture on air quality and that subsequently affects the planning and management of these larger animal production operations.

In response to declining animal production, many states (including Minnesota) in the US have organized task forces and passed legislation to reverse these trends. These groups and programs are trying to promote the economic benefits of animal agriculture and work with producer organizations to reduce the resistance to the growth and educate producers on the proper management of the production operations including environmental concerns, especially air quality. Meanwhile many of the states and federal environmental regulating agencies are being forced by statue and the public to regulate animal production units in a similar fashion to "smokestack" industries because of the "factory" label being placed on production sites with the large number of animals. In order to have the most up to dates emissions values for US animal production, the National Air Emissions Monitoring Study (NAEMS) was recently started that is presently monitoring barn air emissions at five swine, five dairy sites, three egg layer sites, and one broiler site. The NAEMS will help livestock and poultry producers comply with EPA regulations concerning regulated gases and particulate matter by monitoring these pollutants continuously for 24 months, in order to determine which types of farms are likely to emit threshold levels of contaminants under the current regulations. In addition, local units of government (counties and townships) are implementing land use ordinances that often restrict production size or location for a variety of reasons including air quality/odor concerns. The non uniformity of these policies between states and between counties and townships within a state has created an uneven distribution of animal production operations in many sections of the country and in some areas within a state or county that has compounded the air quality issues.

Discussion

Air contaminates

The specific airborne contaminants from animal production sites in the US that are of concern by industry, regulators, and neighbors are odor, gases, dust, insects and microorganisms. The quantity and proportions of these emitted materials are primarily a function of animal species, facility design, and management. Unfortunately, most research to date has focused on the concentrations of constituents within animal buildings due to health concerns for both animals and human workers. Considerably less effort has been committed to quantifying agriculture related air emissions into the surrounding community and eventually the atmosphere.

Odors

Odor from animal production sites is one of the most important factors to consider when planning new, remodeling existing, or managing animal facilities. Probably the simplest explanation for this fact is that odor is readily detectable by anyone (especially neighbors) that has a

Production II

sense of smell. Other airborne emissions may have greater impacts on human health or the environment; however, such emissions often require sophisticated instrumentation for detection. Furthermore, odors are often perceived as indicators of other airborne pollutants.

Odors originate from three primary sources in an animal production system: animal buildings, manure storage units, and land application of manure. Of these three sources, land application of manure is the easiest to manage with respect to control of odor emissions because it typically occurs infrequently and known odor control management practices, such as injection of liquid manure into the soil, are available. Thus, odor emission rate measurements have been and continue to be primarily measured from animal housing facilities and manure storage units.

Most livestock and poultry odors are generated by the anaerobic decomposition of livestock wastes such as manure (feces and urine), spilled feed, bedding materials, and wash water. The organic matter in these wastes is microbial transformed into non-odorous end products under aerobic conditions (Westerman and Zhang, 1997). However, in anaerobic environments, the decomposition of organic compounds results in the production of odorous volatile compounds that is metabolic intermediates or end products of microbial processes (Zhu *et al*., 1999). Many of these compounds can then be transported by airborne dust and other particles (NCARS, 1995) and dispersed into the atmosphere.

Odors evoke a wide range of physiological and emotional reactions. Different people can have very different reactions to the same odor. Odors can be either energizing or calming. They can stimulate very strong positive or negative reactions and memories. Aromatherapy, which is on the increase in the US, illustrates how important odors can be to people. The power, complexity, and our limited understanding of the sense of smell and impact of odor on people makes this an important issue for all the stakeholders involved with pork production.

Gases

Numerous gases are generated in pig housing and manure storage units, which, in addition to odor, should be considered when planning and managing animal production facilities. Kreis (1978) developed one of the earliest lists of volatile compounds associated with the decomposition of livestock and poultry wastes. This research indicated that swine wastes consisted of 50 different compounds. More recently, O'Neill and Phillips (1992) identified 168 different compounds in both swine and poultry wastes.

The identification of gases in livestock and poultry wastes has contributed toward solving problems associated with the indoor air quality of animal production facilities. However, gas emission rate data are imperative for evaluating the impact these gases have on ambient air near animal facilities and potential effects on human health and the environment. Two gases, hydrogen sulfide (H_2S) and ammonia (NH_3), which are generated in animal production systems, are of particular interest. Emission rates for these two compounds have been recorded and their effects concerning the environment and human health are still being studied. Other gases of concern include greenhouse gases such as methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O), and non-methane volatile organics that may contribute to global warming, but only limited emission data from animal operations has been published.

Hydrogen sulfide

Hydrogen sulfide (H_2S) gas is colorless, heavier than air, and has the characteristic odor of rotten eggs that can be detected at concentrations well below 1 ppm. The gas is generated from the anaerobic degradation of manure at animal production sites (Taiganides and White, 1969). High concentrations of H_2S are toxic to both humans and animals (Hartung, 1988): concentrations of 50 ppm can cause dizziness, irritation of the respiratory tract, nausea, and headache. Death from respiratory paralysis can occur with little or no warning at concentrations exceeding 1000 ppm (Field, 1980). The US Occupational Safety and Health Administration (OSHA) have implemented a 10 ppm limit for 8-h H_2S exposures to protect human worker health (ACGIH, 1989). Low levels of H_2S (< 0.2 ppm) has been implemented in causing headaches, nausea, and eye, nose, and throat irritation along with depression and fatigue in chronically exposed people (Schiffman, et al, 1995). No direct environmental problems associated with H_2S emissions have been documented.

Although there are health risks associated with high concentrations of H_2S, concentrations are usually very low in animal housing as compared to concentrations of CO_2 and NH_3. The mean H_2S concentrations in finishing pig houses are typically 0.1 to 0.3 ppm (Heber *et al*., 1997; Muehling, 1970), although concentrations up to 100 ppm can occur in buildings with underfloor concrete manure pits during slurry agitation (Patni and Clarke, 1991).

The odor of H_2S is noticeable at very low concentrations and, therefore, the gas is occasionally used to assess nuisance odors emitted from livestock facilities. Some states, such as Minnesota, have implemented ambient H_2S limits at farm property lines in an attempt to control odor emissions (State of Minnesota). The Minnesota Pollution Control Agency (MPCA) has also randomly checked property line H_2S concentrations at 138 farms throughout Minnesota (MPCA, 1999). Hydrogen sulfide levels were instantaneously measured using a portable Jerome® Hydrogen Sulfide Analyzer (Model 631-X, Arizona Instrument, Phoenix, AZ). Twenty-four of the 138 farms had at least one H_2S measurement that exceeded the 30-ppb regulatory limit. Four of these 24 farms were then continuously monitored for several weeks using single point monitors (SPMs) (MDA Single Point Monitor, MDA Scientific, Zellweger Analytics, Lincolnshire, IL). Only one of these four farms exceeded the 30-ppb standard during the continuous monitoring period.

Ammonia

Ammonia gas is colorless, lighter than air, and has a sharp, pungent odor that is detectable from 5 to 18 ppm. The gas emanates from numerous agricultural sources including livestock and poultry buildings, slurry and manure stores, pastures and land applied with manure. Ammonia release from animal sources is prevalent due to the often-inefficient conversion of feed nitrogen to animal product. As a result, high concentrations of nitrogen are excreted in the urine of pigs and cattle and in the uric acid excreted by poultry.

Ammonia is classified as a particulate precursor, that is as a gas it will react with other compounds to form particulates. Ammonia will also be deposited downwind of sources by both "dry" and "wet" methods, with dry deposition generally occurring locally and wet or "acid rain" occurring regionally. Ammonia may cause several ecological problems in the environment both as it impacts plants and soils from the dry and wet depositions as even building materials such as metal roofs and siding (Bicudo, et al., 2002)

Agricultural sources, and livestock farming in particular, are the largest contributors to NH_3 emissions. Aneja *et al*. (1998) reported that livestock farming comprised approximately 47% of total NH_3 emissions in North Carolina. Therefore, NH_3 emissions from animal production systems should be considered, in addition to odor and H_2S, when planning new or remodeling existing livestock or poultry production farms and the management of them.

Particulate matter

Dust in and around animal facilities consists primarily of feed particles with dried skin, hair or feathers, dried feces, bacteria, fungi, and endotoxins contributing to the mixture (Koon *et al*., 1963; Anderson *et al*., 1966; Curtis *et al*., 1975a; Curtis *et al*., 1975b; Heber *et al*., 1988). Soil particles from open, unpaved feedlots can also be a major constituent of agricultural dust (Algeo *et al*., 1972; Sweeten *et al*., 1988; Sweeten *et al*., 1998). In addition to their contribution to PM, dust particles have been found to adsorb odorous gases, thereby enhancing odor transport and dispersion (Day *et al*., 1965; Hammond *et al*., 1979). Therefore, dust emissions from animal productions systems, especially from outdoor lots, may be a critical factor in managing and planning new facilities for certain animal species and locations.

Flies and other insects

Several types of insects can become abundant during summer months and affect air quality and human comfort in and around animal production facilities. These insects develop in larval breeding sites in animal housing and manure storage units and then disperse as adults into the surrounding landscape. Insect presence can lead to numerous problems depending on insect type. House flies and blowflies can reach annoyance densities and pose a threat to public health. Stable fly bites are painful and irritating to cattle, dogs, horses, and humans. No scientific surveys have been conducted to assess insect abundance at different livestock and poultry enterprises. However, evidence indicates that the abundance of principal insect types associated with animal production depends on supply of and distance to breeding media (Greenberg, 1971; Greenberg, 1973; Skoda and Thomas, 1992).

Biogenic particles

Bacteria, fungi, and endotoxins belong to a broad class of organic particulates known as biogenic particles. High levels of these particles are an indoor air quality concern for both animals and humans. Seedorf *et al*. (1998) indicated that data on the biological half-life of viable microorganisms under varying environmental conditions is needed to predict microbial dispersion and, subsequently, estimate the risk of airborne disease transmission. Heber *et al*. (2001) recently found elevated total aerobic bacteria concentrations up to 600 m from a pig finishing building, although the bacteria were not pathogenic.

Mitigation methods

Animal producers need mitigation methods to lower the impact of airborne contaminants from their pig operations. Some of these methods involve little or no capitol costs while others may require a considerable investment in capitol and labor. The non-capitol mitigation methods may be termed "best management practices" (BMPs). Some typical BMPs often suggested are 1) not to overfeed protein in the animal diets, 2) maintain good housekeeping principles or conditions, 3) have a manure management and/or an odor management plan, 4) maintain a setback distance that will allow sufficient dispersion of odour and gases, and 5) to have a good neighbor policy.

Best management pactices (BMPs)

Animal producers should look carefully at the diets that they are feeding their animals to make sure they are not overfeeding protein or other compounds like sulfur since this can result is considerable higher levels of nitrogen in the manure and the potential for higher levels of odours and gases produced from the barns and associated manure storages (Sutton, et al., 1998 and Shurson, et al., 1998).

Animal production units, both buildings and associated lots and manure storages, should project a clean and pleasant appearance while maintaining good housekeeping practices on the farm. Facilities that are poorly maintained and look dirty and rundown will result in a poor image by neighbors and this can easily be transmitted into more odors complaints and other negative comments and perceptions.

Producers need to stress good housekeeping practices when communicating with employees and when developing and selecting technologies and systems when planning facilities that will result in a clean and well maintained operation.

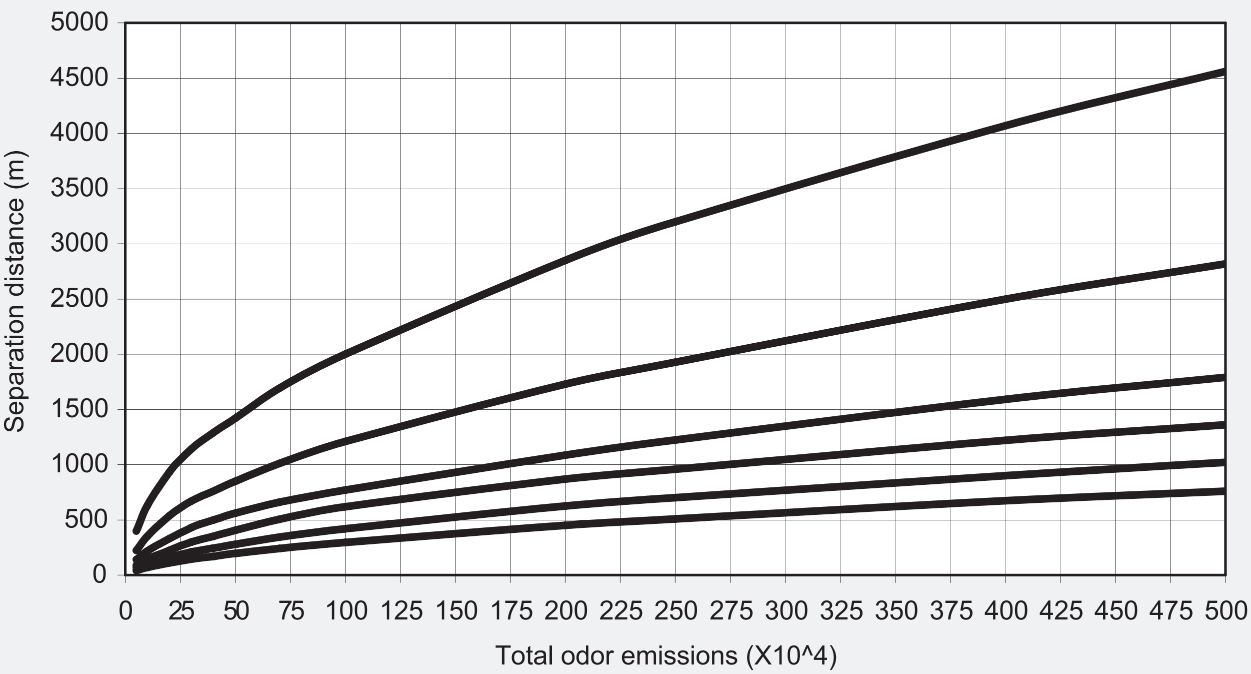
Just as animal operations need to have a plan on how they intend to handle manure produced on their farm (manure management plan) they also need to have a plan on how they plan to handle odor that is created by their operation. As manure management plans document the proper handling and application of manure onto cropland, odor management plans need to identify odor sources on the farm, determine which source is most likely to bring about an odor complaint, list one or two control strategies for each of the significant sources, and establish criteria to implement these strategies (Schmidt, et al., 2001)

Dispersion modeling has been used to predict the concentration of odors and other pig housing contaminants downwind from production site since the early 1980s (Janni, 1982; Carney and Dodd, 1989; Ormerod, 1991; Chen *et al*., 1998; Jacobson *et al*., 2003; Hoff and Bundy, 2003a; Koppolu, *et al.,* 2002). The use of dispersion models to assist in the determination of setback distances based on air quality criteria requires knowledge of odor emission data from animal buildings and associated manure storage units, long-term meteorological data, and the tolerance level of neighbors for livestock odors.

One of the methods used the INPUFF-2 air dispersion model to develop the Odor from Feedlots-Setback Estimation Tool (OFFSET) in Minnesota (Jacobson *et al*., 2005; Guo *et al.,* 2005). OFFSET was developed as a tool to estimate the frequency of annoying odors at various distances from an animal production site. The OFFSET method is a step-by-step process that systematically uses empirical field odor emissions as well as weather data for a given geographic area and predicts the setback distance required for several odor annoyance free frequencies levels. The first step is to identify all the odour sources at an animal production site. The next step is selecting, from tabulated values, the odor emission number on a per area basis for buildings or manure storage units and simply determining the total surface area of the barns follows these and/or storage units, credit any odour control technology, and then calculate the total odour emission factors for each source (Jacobson, *et al*., 2001). Setback distances from animal sites for Minnesota weather conditions are presented in graph form (Figure 1) as a function of the total odor emission factor and the desired odor annoyance free frequency for neighbors and/or the surrounding community. (Figure 1)

Establishing and maintaining a "good neighbor" policy is essential to a well-planned strategy when building a new, expanding existing, or managing animal production units. Producers need to maintain a positive relationship with neighbors and the public in general. It is much easier to avoid nuisance complaints all together rather than correct them once they occur. Producers need to respect and appreciate neighbors concerns about how a pig operation will affect their quality of life and property values. Some

Figure 1: Estimated setback distances from animal production sites at different odor annoyance free requirements of surrounding community and leeward of the prevailing wind from animal operations for Minnesota weather conditions.



Production II

of the things that the manager of a livestock operation needs to consider are:

Location and visibility of the operation from:

- roads
- neighbors
- parks, schools, churches, or other public places

Prevailing winds and topography and how neighbors might be affected by odors generated from your operations.

Developing a landscape plan at your site that reduces the visual and olfactory impact of your operation from the road and other public areas. Plant materials and earthen berms can reduce the sight and the impact of odors on neighbors and individuals driving by.

Complying with all regulations and possibly even exceeded these if physically possible since this will send a strong message that you are aware of the issues and take them seriously..

Support your local community with your business by buying locally if feasible and also helping with local events like school and community celebrations and local charities.

Finally, communication with neighbors is essential when planning for and managing a pig operation. Make sure that all neighbors know you have complied with the regulations and have manure and odor management plans. Offer tours of your operation, within biosecurity concerns, to neighbors and/or other officials and regulators. Establish a complaint system and encourage people to contact you first if they detect odors or have other complaints. Always respond to any complaint no matter how trivial and if mistakes are made at your operation, take responsibility and take the appropriate corrective actions. Good communication with neighbors will go a long way to avoiding problems with issues like odor complaints from neighbors but remember you may not always thing your treatment is fair or as you would like it to be.

Capitol investments control technologies

Utilizing BMPs will only do so much in avoiding complaints or regulatory mandates and standards. In some cases, air quality or odor control technologies may be needed to reduce their impact of your operation on the surrounding community. A list of some typical technologies is given in Table 1.

The use of any of the above technologies needs to be carefully analyzed to make sure it is targeted to one of the significant odour, gas, or PM emission sources on the farm. Capitol as well as operating costs and labor is obvious considerations along with the estimated effectiveness of the technology in reducing odor or other air emissions. Unfortunately, many of the above technologies are still being evaluated by universities and other research agencies, therefore an animal operation needs to make sure a technology is appropriate for your facilities and it has a reasonable chance of delivering positive results.

Summary and conclusions

The management of animal production operations in the United States has been fundamentally changed by the concern over outdoor air quality concerns. Planning of new or expanding existing pig production units needs special attention to these growing air quality issues. The outdoor air quality concerns of neighbors and surrounding communities has changed some of the fundamental designs of intensive animal operations in the US. An example would be the banning of earthen manure storage basins or lagoons in Minnesota for pig production units. Manure in swine production operations must be stored either in below or above ground concrete or metal storage units.

Environmental and the air quality/odor issue specifically, will continue to force the location of pig operations in the US away from more populated areas and maybe from certain type of landscapes. It will become commonplace to run air or odor dispersion models before facilities are built as part of the planning and regulatory process. This has already occurred in certain parts of the country and it will expand rapidly. Also, existing animal facilities impacts on the local air quality will continue to be scrutinized by neighbors and the public and managers of these operations will be challenged to meet and exceed their expectations and the regulator's standards.

References

1. Algeo, J. W., C. J. Elam, A. Martinez, and T. Westing. 1972. How to Control Feedlot Pollution: Bulletin D. Bakersfield, CA: California Cattle Feeders Association.

2. ACGIH (American Conference of Governmental Industrial Hygienists). 1989. Guide to Occupational Exposure Values. Cincinnati, OH.

3. Anderson, D. P., C. W. Beard, and R. P Hanson. 1966. Influence of poultry house dust, ammonia, and carbon dioxide on the resistance of chickens to Newcastle disease virus. *Avian Diseases* 10(2): 177–188.

4. Aneja, V. P., G. C. Murray, Jr., and J. Southerland. 1998. Atmospheric nitrogen compounds: emissions, transport, transformation, deposition and assessment. *Environmental Manager*. pp. 22–25.

5. Bicudo, J.R., D.R. Schmidt, S.L.Wood-Gay, R.S. Gates, L.D. Jacobson, S.J. Hoff. 2002. Air Quality and Emissions from Livestock and Poultry Production/Waste Management Systems. White paper and Recommendations. National Center for Manure and Animal Waste Management, North Carolina State University, Raleigh, N.C. 56 p.

6. Carney, P. G. and V. A. Dodd. 1989. A comparison between predicted and measured values for the dispersion of malodours from slurry. *Journal of Agricultural Engineering Research* 44(1): 67–76.

Table 1: Odour and Air Quality Control Technologies. (Schmidt, et.al. 2001)

System	Description
Biofilters	Odorous gases are passed through a bed of compost and wood chips; bacteria and fungal activity help oxidize organic volatile compounds.
Biological and chemical wet scrubbers	Odorous gasses are passed through a column packed with different media types; water (and/or chemical) is sprayed over the top of the column to help optimize biological and chemical reactions.
Diet manipulation*	Enzymes added to diet to improve nutrient utilization; diets formulated to reduce crude protein content; or other changes in diets to enhance digestion.
Fat added to feed	Dust reduction and subsequent odor reduction by adding fat to the feed.
Manure additives*	Chemical or biological products are added to the manure.
More frequent manure removal*	Fresh manure (fewer than 5 days old) produces fewer odors than stored manure.
Nonthermal plasma	Odorous gases are oxidized when passed through plasma.
Oil sprinkling	Vegetable oil is sprinkled daily at low levels in the animal pens.
Ozone*	Ozone is added to the ventilation air to oxidize the odors.
Shelterbelts*	Rows of trees and other vegetation are planted around a building, thus creating a barrier for both dust and odorous compounds emitted from the building exhaust.
Windbreak walls*	A solid or porous wall constructed 10 to 15 feet from the exhaust fans will cause dust to settle out and will also help disperse the odor plume.
Aerobic treatment	Biological process where organic matter is oxidized by aerobic bacteria; mechanical aeration is required in order to supply oxygen to the bacterial population.
Anaerobic digestion*	Biological process where organic carbon is converted to methane by anaerobic bacteria under controlled conditions of temperature and pH.
Floating clay balls	Floating clay balls cover the manure surface.
Geotextile cover	Geotextile membranes are placed over the surface of the manure.
Manure additives*	Chemical or biological products are added to the manure to reduce gas formation.
Natural crust	Dairy and sometimes swine storage basins can form a natural crust. This crust will reduce odor emissions.
Solid cover	Non-porous cover floated on, or suspended over, the liquid surface. Covers trap gases before they escape. Gases must be drawn off and treated.

Table 1: Continued

Solid composting	Biological process in which aerobic bacteria convert organic material into a soil-like manure called compost; itÕs the same process that decays leaves and other organic debris in nature.
Solid separation*	Solids are separated from liquid slurry through sedimentation basins or mechanical separators.
Straw cover	An 8-12 inch blanket of dry wheat, barley, or other good quality straw floated on the manure surface reduces emissions.
Manure incorporation or injection	Manure is incorporated immediately after land application or manure is injected under the soil surface.
Chemical addition	Chemicals added during agitation to reduce hydrogen sulfide or ammonia emissions.
Mortality composting	Method to dispose of dead animals. Carcasses are buried in sawdust or some other organic composting material. Decomposition takes place very rapidly.

*Effectiveness of these technologies has not been verified.

7. Chen. Y. C., D. S. Bundy, and S. Hoff. 1998. Development of a model of dispersion parameters for odour transmission from agricultural sources. *Journal of Agricultural Engineering Research* 69: 229–238.

8. Curtis, S. E., J. G. Drummond, D. J. Grunloh, P. B. Lynch, and A. H. Jensen. 1975a. Relative and qualitative aspects of aerial bacteria and dust in swine houses. *Journal of Animal Science* 41(5): 1512–1520

9. Curtis, S. E., J. G. Drummond, K. W. Kelley, D. J. Grunloh, V. J. Meares, H. W. Norton, and A. H. Jensen. 1975b. Diurnal and annual fluctuations of aerial bacterial and dust levels in enclosed swine houses. *Journal of Animal Science* 41(5): 1502–1511.

10. Day, D. L., E. L. Hansen, and S. Anderson. 1965. Gases and odors in confinement swine buildings. *Transactions of the ASAE* 8(1): 118–121.

11. Field, W.E. 1980. Rural health and safety guild: beware of on-farm manure storage hazards. Volume S-82. West Lafayette, IN: Cooperative Extension Service, Purdue University.

12. Greenberg, B. 1973. *Flies and Disease: Volume II. Biology and Disease Transmission*. Princeton, NJ: Princeton University Press.

13. Greenberg, B. 1971. *Flies and Disease: Volume I. Ecology, Classification and Biotic Associations*. Princeton, NJ: Princeton University Press.

14. Guo H., L.D. Jacobson, D.R. Schmidt, R.E. Nicolai, J. Zhu, K.A. Janni. 2005. Development of OFFSET Model for Determination of Odour Annoyance Free Setback Distance from Animal Production Sites, Part II: Model Development and Evaluations. Transactions of the ASAE, Vol. 48(6): 2269–2276.

15. Hammond, E. G., C. Fedler, and G. Junk. 1979. Identification of dust-borne odors in swine confinement facilities. *Transactions of the ASAE* 22(5): 1186–1189, 1192.

16. Hartung, J. 1988. Tentative calculations of gaseous emissions from pig houses by way of the exhaust air. In *Volatile Emissions from Livestock Farming and Sewage Operations*, eds. O. Noren, J. Voorburg, and P. L'Hermite, 54–58. New York: Elsevier Applied Science.

17. Heber, A.J., 1997. Setbacks for sufficent swine odor dispersion and dilution. Presented at Livestock and Environment Symposium, University of Nebraska Cooperative Extension Service, New World Inn, Columbus, NE, Dec. 10–11, 1997. Modified Dec. 16, 1997.

18. Heber, A.J., R.K. Duggirala, J.Q. Ni, M.L. Spence, B.L. Haymore, V.I. Adamchuck, D.S. Bundy, A.L. Sutton, D.T. Kelly, and K.M. Keener. 1997. Manure treatment to reduce gas emissions from large swine houses. In *Proc. International Symposium on Ammonia and Odour Control from Animal Production Facilities*, eds. J.A.M. Voermans and G. Monteny, 449–57. Vinkeloord, The Netherlands. Rosmalen, The Netherlands: NVTL. 2.

19. Heber, A. J., M. Stroik, J. M. Faubion, and L. H. Willard. 1988. Size distribution and identification of aerial dust particles in swine finishing buildings. *Transactions of the ASAE* 31(3): 882–887.

20. Hoff, S.J. and D.S. Bundy. 2003. Modeling odor dispersion from multiple sources to multiple receptors. In: Proceedings of the International Symposium on Gaseous and Odous Emissions from Animal Production Facilities. Horsens, Denmark. June 1–4, 2003. pp 331–339.

21. Jacobson, L.D., H.Guo, D.R. Schmidt, R.E. Nicolai, J. Zhu, K.A. Janni. 2005. Development of OFFSET Model for Determination of Odour Annoyance Free Setback Distance from Animal Production Sites, Part I: Review and Experiment. Transactions of the ASAE, Vol. 48(6): 2259–2268.

22. Jacobson, L., D. Schmidt, and S. Wood. 2001. OFFSET: Odor from feedlots setback estimation tool. #FO-07680-C. University of Minnesota Extension Service. St. Paul, MN.

23. Jacobson, L.D., H. Guo, D.R. Schmidt, R.E. Nicolai & J. Zhu. 2003. Development of OFFSET (Odor from Feedlots-Setback Estimation Tool) for Determination of Odor Annoyance Free Setback Distances form Animal Production Sites, In proceedings of the Inter. Symposium on Gaseous & Odour Emissions from Animal Production Facilities held in Horsens, Denmark, June 1–4, 2003. p. 320 - 330.

24. Janni, K. A. 1982. Modeling dispersion of odorous gases from agricultural sources. *Transactions of the ASAE* 25(6): 1721–1723.

25. Koon, J., J. R. Howes, W. Grub, and C. A. Rollo. 1963. Poultry dust: origin and composition. *Agricultural Engineering* 44(11): 608–609.

26. Koppolu, L., D.D. Schulte, S. Lin, M.J. Rinkol, D.P. Billesbach and S.B. Verma. 2002. Comparison of AERMOD and STINK for dispersion modeling of odorous compounds. ASAE Paper No. 02–4015. St. Joseph, MI: ASAE.

27. Kreis, R. D. 1978. Control of animal production odors: the state-of-the-art. EPA Environmental Protection Technology Series; EPA-600/2–78–083. Ada, OK: Environmental Protection Agency, Office of Research and Development.

28. MPCA (Minnesota Pollution Control Agency). 1999. Feedlot air quality summary: data collection, enforcement and program development. St. Paul, MN

29. Muehling, A. J. 1970. Gases and odors from stored swine waste. *Journal of Animal Science* 30: 526–530.

30. NCARS (North Carolina Agricultural Research Service). 1995. Options for managing odor: a report from the Swine Odor Task Force. Raleigh, NC: North Carolina State Agricultural Research Service and North Carolina State University.

31. Ormerod, R. J. 1991. Modeling emissions and dispersion of feedlot odour: a case study. the dispersion of agricultural odors. Proceedings of a workshop on agricultural odours. Toowomba, Queensland, Australia. Feedlot Services Group, Queensland Department of Primary Industries, AMLRDC Report No. DAQ 64/7.

32. O'Neill, D. H. and V. R. Phillips. 1992. A review of the control of odour nuisance from livestock buildings. 3. Properties of the odorous substances which have identified in livestock wastes or in the air around them. *Journal of Agricultural Engineering Research* 53(1): 23–50.

33. Patni, N. K. and S. P. Clarke. 1991. Transient hazardous conditions in animal buildings due to manure gas released during slurry mixing. *Applied Engineering in Agriculture* 7(4): 478–484.

34. Schiffman SS, Sattely-Miller E, Suggs MS, Graham BG. 1995. The effect of environmental odors emanating from commercial swine operations on the mood of nearby residents. Brain Research Bulletin 37(4):369–75.

35. Schmidt, D., L. Jacobson, K. Janni. 2001. Preparing an odor management plan. Publication # FO-7637-C, 8 pgs. University of Minnesota Extension Service. St. Paul, MN.

36. Seedorf, J., J. Hartung, M. Schroder, K. H. Linkert, V. R. Phillips, M. R. Holden, R. W. Sneath, J. L. Short, R. P. White, and S. Pederson. 1998. Concentrations and emissions of airborne endotoxins and microorganisms in livestock buildings in Northern Europe. *Journal of Agricultural Engineering Research* 70(1): 97–109.

37. Shurson, J., M.R. Whitney, and R. Nicolai. 1998. Nutritional manipulation of swine diets to reduce hydrogen sulfide. A project report to the Minnesota Department of Agriculture.

38. Skoda, S. R. and G. D. Thomas. 1992. The stable fly as a pest of humans. Agricultural Research Division, Institute of Agriculture & Natural Resources, University of Nebraska, Lincoln.

39. State of Minnesota. Hydrogen Sulfide Standard. Minn. R. 7009–0080.

40. Sutton, A.L., J.A. Patterson, O.L. Adeola, B.A. Richert. D.T. Kelly, A.J. Heber, K.B. Kephart. R. Mumma., and E. Bogus. 1998. Reducing sulfur containing odors through diet manipulation, In Proceedings: *Animal Production Systems and the Environment* 1998a 125–130. Des Moines, IA. July 19–22.

41. Sweeten J. B., C. B. Parnell, B. W. Shaw, and B. W. Auvermann. 1998. Particles size distribution of cattle feedlot dust emission. *Transactions of the ASAE* 41(5): 1477–1481.

42. Sweeten, J. B., C. B. Parnell, R. S. Etheredge, and D. Osborne. 1988. Dust emissions in cattle feedlots. Veterinary Clinics of North America: Food Animal Practice 4(3): 557–578.

43. Taiganides, E. P. and R. K. White. 1969. The menace of noxious gases in animal units. *Transactions of the ASAE* 12(3): 359.

44. Westerman, P. J. and R. H. Zhang. 1997. Aeration of livestock manure slurry and lagoon liquid for odor control: a review. *Applied Engineering in Agriculture* 13(2): 245–249.

45. Zhu, J., G. L. Riskowski, and M. Torremorell. 1999a. Volatile fatty acids as odor indicators of swine manure - a critical review. *Transactions of the ASAE* 42(1): 175–182.