OVERVIEW OF DIFFERENT LAGOON EFFLUENT APPLICATION METHODS ON ODOR AND AMMONIA EMISSIONS

Garry Grabow
Assistant Professor
Department of Biological and Agricultural Engineering
North Carolina State University
Campus Box 7625
Raleigh, North Carolina 27695-7625
e-mail Garry_Grabow@ncsu.edu

Background

In recent years, there has been an increasing emphasis on controlling odor from animal operations. Historically, animal operations have been exempted from odor regulations in North Carolina, and no stipulations regarding odor emissions or their abatement are contained in animal waste management system permits. However, as part of a waste utilization plan (WUP), a part of the overall certified animal waste management plan (CAWMP), an odor "checklist" must be completed and submitted. Only three of seventeen listed odor sources in the checklist are related to land application, and two of those three relate to slurries or sludge. While not currently regulated through the permitting process of animal operations, there is a mechanism in place to allow registering of complaints due to objectionable odors from animal operations, for follow-up inspections of the complaints, and evaluation and recommendation to be made by the Division of Air Quality (DAQ). As such, air quality enforcement is complaint-driven. DAQ may require the owner or operator of an animal facility to submit information pursuant to the complaint. In addition, the Director may require a best management plan for controlling odors. If the plan fails either by lack of submission of the plan or non-implementation of the plan, the Director may require the owner or operator of the facility to submit an application for a "control technology" permit. Only at this point does air quality have a permit directly associated with it. On a federal level, the USEPA, under the recent "consent decree", has initiated monitoring of selected animal operations in order to obtain baseline figures of ammonia emissions. However, emissions from land application will be exempt from any regulations resulting from this monitoring. Concurrent with State and Federal pressure to reduce ammonia emissions and odor are changing demographics in North Carolina that have included the construction of homes and subdivisions in closer proximity to agricultural operations. These factors have combined to spur efforts to reduce odor and ammonia emissions from animal operations.

Liquid Waste Characteristics

Swine anaerobic lagoon effluent is low in solids (around 0.5%) and contains on average about 128 pounds per acre-inch (4.7 pounds per 1,000 gallons or 565 mg/l) of total nitrogen (Barker, 1994). These values range widely depending upon type of swine operation, season, and other factors. Ammonia comprises approximately 80% of total nitrogen in swine lagoon effluent and the rest is in organic form. Little to no nitrate is contained in swine lagoon effluent. While anaerobic lagoon effluent contains a relatively large amount of ammonia, there are many other compounds that contribute to odor. Over 300 compounds that contribute to odor have been identified in hog waste, including ammonia, hydrogen sulfide, and volatile organic compounds

(VOCs) (Schiffman et al., 2001). While very few of these compounds can be detected on their own, synergistic effects and transformations can increase odor.

Ammoniacal nitrogen is comprised of ammonia (NH_3) - sometimes referred to as un-ionized ammonia - and ammonium (NH_4^+), the proportion of which is controlled by pH. Ammonia (NH_3) can be lost through volatilization and is the odor-producing form of ammoniacal nitrogen and its proportion increases with increasing pH. At a pH of 9.0 ammonia and ammonium concentrations are equal. At a pH of 7.0, only 0.57% is in the form of ammonia. The average pH of anaerobic swine lagoon effluent is about 7.8 and ranges from about 6.5 to 8.5 (Barker, 1994). At a pH of 7.8, ammonia is about 3% of ammoniacal nitrogen.

Mechanisms that control ammonia and odor emissions

A variety of factors affect odor and ammonia losses during land application. These include application equipment type, crop, weather, soil properties and conditions, and animal waste properties. Most lagoon effluent in North Carolina is applied either through irrigation-type equipment or by hose-drag-type equipment. Land application is also done with tanker/spreaders that may broadcast or inject liquid manure but that type of equipment is more commonly used with slurries rather than with lagoon liquid. Weather affects not only the odor and ammonia emissions from the land application equipment to the ground, but also affects emissions after application. Dry, windy conditions promote ammonia loss – however, odor is generally more noticeable under humid conditions. Crop condition can affect ammonia loss too. Dense, high crop canopies can increase odor and ammonia loss if effluent is applied "over the top" but will reduce odors if applied beneath the canopy (drop tubes or injected). Soils factors such as pH, cation exchange capacity (CEC), infiltration rate and soil-moisture content can affect odor and ammonia loss. Lower pH soils (more acidic) will have lower ammonia loss rates; soils with high CEC will also lose less ammonia due to binding of ammonia on exchange sites, and low infiltration rates and high soil moisture content will increase ammonia losses since infiltration will be impeded. Nutrient content and pH of lagoon effluent will also impact ammonia losses. Ammonia losses increase with increasing nutrient (particularly N) content and increasing pH.

Equipment Options

Irrigation-Type Equipment

Most swine anaerobic lagoon effluent in North Carolina is land-applied with irrigation equipment. Irrigation systems included in this category are solid set sprinklers, hard hose and cable-tow traveling systems, center pivots, and boom-type sprayers. Two basic mechanisms affect odor and ammonia loss in these systems; evaporation and drift. Several factors may contribute to evaporation and drift. These include nozzle size and type, operating (nozzle) pressure, and height of nozzle.

Evaporation in spray irrigation is limited by the energy available to convert water from a liquid to vapor phase. That amount is estimated to be in the 1 to 2 percent range (Christiansen, 1937; Thompson et al., 1997). Measurements of evaporation in the field have ranged from less than one percent to ten percent for drop type nozzles (Schneider, 2000) to 20 percent for impact-type sprinklers including big-guns. The latter figure reflects total losses and therefore includes drift. Evaporation also occurs once the liquid contacts the crop canopy or ground. These losses are harder to quantify.

Nozzle size and type, and operating pressure determine droplet size of the effluent being land applied. Smaller droplets result in greater evaporation and drift compared to larger droplets.

Smaller nozzles and higher pressures result in small droplet size. Kohl (1974) found that mean droplet size was 1.75 mm at 43 psi and 1.5 mm at 58 psi for a 7/64 inch nozzle while for a 5/32 inch nozzle the average droplet diameters were 2.1 and 1.7 mm respectively for the same pressures. Kincaid et al. (1996) developed relationships between operating pressure, nozzle size and droplet sizes for impact and drop-type nozzles. Using their relationship, median droplet size for a 0.5 inch nozzle (at the low end of the range of "big gun nozzles") is 4.8 mm at a nozzle pressure of 50 psi and 3.1 mm for a nozzle pressure of 100 psi. Since the falling rate of a droplet is proportional to its diameter squared, a droplet of 1 mm diameter will travel roughly four times as far as one of 4 mm diameter. Nozzle type can also affect droplet size in "big-guns" found on hard-hose traveler and cable-tow systems. Ring nozzles tend to break up the spray pattern more than taper-ring or taper-bore type nozzles, and therefore tend to increase odor and ammonia loss. Drop-type sprinklers have been developed for center pivots. These nozzles operate under lower pressure (typically 10-30 psi) than impact sprinklers (35-70 psi), and big gun systems (50-100 psi), and distribute effluent by dispersing a stream on a inverted splash plate. Some of these nozzles are manufactured specifically for wastewater as they are specifically designed to pass solids.

Nozzle height can substantially impact odor and ammonia emissions. Greater distances form the ground to the nozzle result in greater evaporation and drift. Nozzle height is more important for larger droplets as small droplets can actually rise with upward air motion. Center pivots can either use impact sprinklers mounted on top of the boom, or use nozzles suspended on drop hoses below the boom. The combination of a low nozzle height and low pressure translate to low drift from center pivot or boom-type systems using drop nozzles. Shaffer and Aldrige (2003) found drift to be greatest with a hard hose traveling system and lowest with a center pivot system with drop nozzles in a study conducted in Raleigh, NC.

<u>Hose-Drag-Type Equipment</u>

Recently, hose-drag type equipment (also sometimes referred to as drag-hose) has become popular in North Carolina. The unit is pulled by a tractor and either attached to a hard hose reel or to flexible hose. Distribution of liquid manure to the units is normally accomplished with pumps at the lagoon and buried main lines and hydrants; similar to a hard hose traveler supply system. Odor and ammonia emissions during land application from this type of equipment is reduced compared to irrigation-type equipment due to two factors; low pressure at the discharge point (just a few pounds), and discharge close to the ground. Most of these units also incorporate aeration tines that aerate the soil and promote infiltration that also aids in odor and ammonia loss reduction. Liquid manure is dispensed as a "sheet" of water rather than droplets from either hooded outlets or splash plates.

Variations of this type of equipment include boom type equipment that broadcast a wider wetted width under slightly higher pressure, much like the distribution of a tanker by with two outlet nozzles. A typical nozzle diameter on this type of unit ranges between two and three inches.

Management Options

A number of management options are available to reduce emissions of odor and ammonia. Land applying in summer and fall can result in less odor due to greater biological activity both in the liquid manure and in the soil. Application during daytime may reduce odors compared to early morning or evening. This is because the air is "stable" in the early morning and little mixing occurs. A temperature inversion is an example of extremely stable conditions. When the air heats up over the course of the day, it becomes unstable, the air mixes and odor dissipation is greater. However, the mixing that promotes dissipation of odor over and near the land application field may be accompanied by wind that picks up over the course of the day and transports odors off-site to neighboring property. If irrigation equipment is used to land apply, care should be taken not to land apply during windy conditions. The general recommendation is not to apply in winds averaging more than five miles per hour.

Other "common sense" options are not to land apply when social events are held nearby such as on weekends and holidays. It may also be prudent to inform neighbors when you plan to land apply.

Research in North Carolina

Previous

Research on ammonia losses from land application has been conduction in North Carolina over the past 30 years. These studies have looked at ammonia loss through two mechanisms that may occur during land application; loss of effluent volume via evaporation and drift, and decrease in ammonia concentration in the liquid from the lagoon to the ground. Westerman et al (1983) found an average of 19% ammonia loss from a solid set system during land application onto coastal bermudagrass. Estimated ammonia loss was based upon change in concentration between the lagoon and catch cans. Irrigation was done at night in this study and evaporation was found to be negligible. In a study conducted during the same time period (1977-79) Safley et al (1993) found a 30% loss of ammonia also from a solid set irrigation system land applying to coastal bermudagrass. In this study loss was calculated based upon mass rather than concentration; considering volume recovered in catch cans and change in ammonia concentration. A study done with big gun irrigation found a 3% loss of ammonia from land application onto bare soil based upon the change in ammonia concentration between the lagoon and catch cans (Safley et al., 1992). Results for center pivot irrigation using impact sprinklers under the same conditions showed a 5% loss of ammonia based upon concentration and a 26% loss of ammonia based upon mass (change in concentration times volume lost). A later study found a 6% loss of ammonia from big gun irrigation on coastal bermudagrass based upon concentration. In this study evaporation was found to range between 2 and 8 percent (Westerman, 1995).

Recent

A study contrasting ammonia losses between big gun irrigation and a hose-drag type system has been recently completed. Unlike the aforementioned studies that sought to quantify ammonia loss only from the lagoon through the irrigation system to the ground, instrumentation was setup to collect air samples over plots receiving liquid swine manure for several days after land application occurred. While ammonia emission during irrigation was much lower than some previously published studies, total ammonia loss was similar. Most loss occurred during the first four hours after the irrigation event. Little to no ammonia loss was found between the big gun and the catch cans. Average ammonia losses from four big gun trials were 22% while average ammonia loss for three hose-drag trials was about 6%. These findings confirm the ability of hose drag systems to reduce odor and ammonia emissions compared to a big-gun system.

Table 1 Relative Effectiveness of Various Equipment Used to Land Apply Swine Effluent from Anaerobic lagoons in limiting odor and ammonia loss. Relative Uniformity and Application Timeliness are also shown[1].

System Type	Ammonia Conservation[2]	Limit Odor	Uniformity of Application	Timeliness of Application[3]
Solid set	Poor	Poor	Good	Good
Big -gun	Very poor	Very poor	Good	Good
Center Pivot – impact sprinklers	Very poor	Very poor	Excellent	Excellent
Center Pivot/Boom with drop nozzles	Good	Good	Excellent	Excellent
Hose Drag	Excellent	Excellent	Fair	Excellent

[1]Table adapted from Livestock and Poultry Environmental Curriculum, using various sources
[2]Better ammonia conservation means less ammonia loss
[3]Timeliness of application implies moving large quantities of effluent in a short time period for management flexibility and considering field accessibility (trafficability).

References

Barker, J. C., J.P. Zublena, and F.R. Walls. 1994. Animal and Poultry Manure Production and Characterization. North Carolina Cooperative Extension Service. Revised 2001.

Christiansen, J.E. 1937. Irrigation by sprinkling. Agricultural Engineering 18(12): 533-538.

Kincaid, D.C., K.H. Solomon, and J.C. Oliphant. 1996. Drop size distributions for irrigation sprinklers. Transactions of the ASAE 39(3):839-845.

Kohl, R.A. 1974. Drop size distribution from medium-sized agricultural sprinklers. Transactions of the ASAE

Thompson, A.L., D.L. Martin, J.M. Norman, J.A. Toplk, T.A. Howell, J.R. Gilley, and A.D. Schneider. 1977. Testing of a water loss distribution model for moving sprinkler systems. Transactions of the ASAE 40(1):81-88.

Safley, L.M Jr., J.C. Barker, and P.W. Westerman. 1988. Ammonia loss from irrigation of anaerobic lagoon liquid. ASAE meeting paper no. 88-2574 presented at the 1988 international winter meeting of the American Society of Agricultural Engineers, Chicago, IL, Dec. 13-16.

Safley, L.M Jr., J.C. Barker, and P.W. Westerman. 1993. Loss of nitrogen during sprinkler irrigation of swine lagoon liquid. Bioresource Technology 40(1992) pp. 7-15.

Schneider, A.D. 2000. Efficiency and uniformity of the LEPA and spray sprinkler methods: A review. Transactions of the ASAE 43(4):937-944.

Safley, L.M., Jr., S.L. Crawford, P.W. Westerman, and R.L. Mikkelson. 1993. Ammonia volatilization from irrigated application of anaerobic lagoon liquid. N.C. Agricultural Research Project.

Shaffer, K.A. and F. Aldridge. 2003. Wastewater irrigation system selection to meet uniformity, odor, and drift concerns. ASAE meeting paper no. 032249 presented at the 2003 annual international meeting of the ASAE, Las Vegas, NV, 27-30 July.

Schiffman, S.S., J.L. Bennett, and J.H. Raymer. 2001. Quantification of odor and odorants from swine operations in North Carolina. Agric. Forest Meterol. 108:213-240.

Westerman, P.W., J.C. Burns, M.R. Overcash, and R.O. Evans. 1983. Swine lagoon effluent applied to coastal bermudagrass. EPA-600/2-84-004. No. PB 83-152 264. NTIS, Springfield, VA. 213 pp.

Westerman, P.W., R.L. Huffman, and J.C. Barker. 1995. Environmental and agronomic evaluation of applying swine lagoon effluent to coastal bermudagrass for intensive grazing and hay. In: Proceedings of Seventh International Symposium on Agricultural and Food Processing Wastes. June 18-20, 1995, Chicago, IL. ASAE publication 7-95, ASAE, St. Joseph, MI.