Recent Developments in Air Quality from Dairies and Cattle Feedyards

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Abstract

The air pollutants of greatest concern to the owners, managers and neighbors of open-lot livestock facilities are particulate matter (PM) and ammonia (NH_3). Other gaseous constituents, as well as bioaerosols, are of concern at the local, regional and state levels, but most of the effort and resources devoted to open-lot air quality at the federal level has focused on PM and NH_3. This paper outlines some of the major research developments since 2003 concerning emissions and abatement of those two important classes of air pollution.

Recent Advances

Ammonia

Emissions

Magnitude and Significance. Among the gaseous emissions traceable to dairies and cattle feedyards, the highest profile in environmental air quality is reserved for NH_3. Dairymen and cattle feeders who have been attending closely to federal regulatory developments and litigation understand that the primary reason for NH_3's high profile is the recent proliferation of lawsuits under the Emergency Planning and Community Right-to-Know Act (EPCRA). Plaintiffs in those lawsuits assert that (a) the routine airborne emissions of NH_3 from many animal-feeding operations (AFOs) exceed the monitoring and reporting threshold of 100 lb/d and that (b) any such AFO that has not been monitoring and reporting its NH_3 emissions should be penalized similarly to the industrial sources for whom EPCRA and its Superfund siblings were originally written. Figure 1 shows the approximate capacity of a cattle feedyard that would surpass the 100 lb/d threshold depending on the feedyard's aggregate nitrogen-use efficiency. When one realizes that the average capacity of a cattle feedyard in the Texas Panhandle exceeds 35,000, Figure 1 illustrates at least three take-home messages:

1. Assuming a modestly optimistic industry-wide N-use efficiency of 70%, all of the commercial cattle feedyards larger than about 500 head (which is to say, virtually all of the cattle feedyards in the region) would be subject to the EPCRA monitoring and reporting requirements.

2. The N-use efficiency that would be required for a 35,000-hd feedyard to emit less than 100 lb/d of NH_3 would be about 99.5%. To achieve that kind of efficiency would undoubtedly require abandoning the open-lot production system in which virtually all beef cattle in the Great Plains and West are fed.

3. Even aside from the infrastructure cost of shifting to full confinement systems, even *documenting* N efficiency at the first decimal place (i. e., 99.5% vs. 99%) would be prohibitively expensive for the cattle-feeding industry.

For dairies, the qualitative picture is much the same, although differences in ration, physiology, production and manure-handling systems shift the absolute numbers one way or the other.

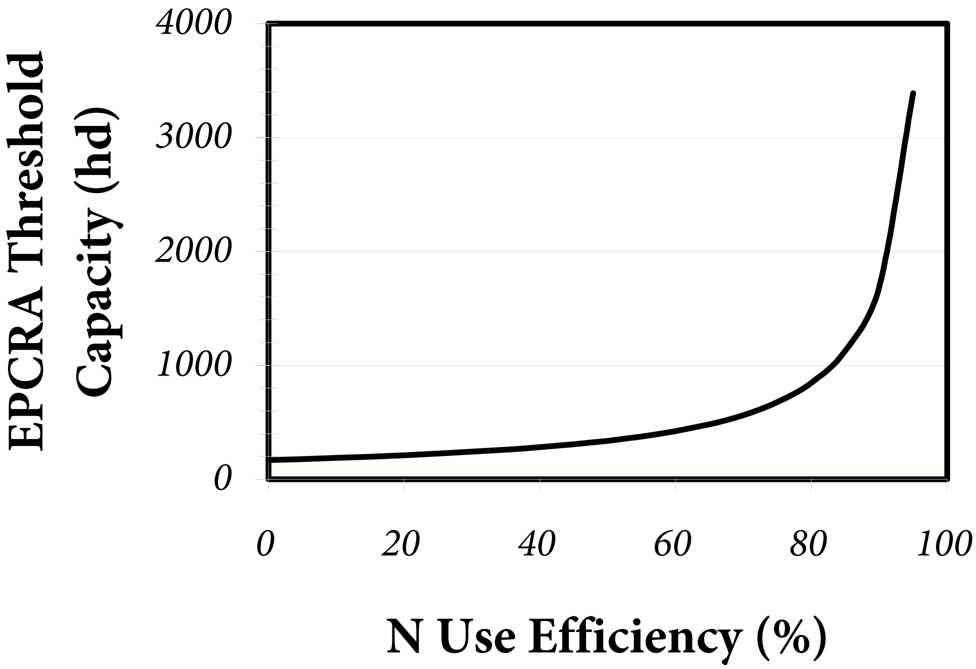

Figure 1. Approximate capacity of cattle feedyards that would meet the 100 lb/d monitoring and reporting threshold under EPCRA for various nitrogen-use efficiencies.

Recent Legislation. In October 2005, U. S. Senators Sam Brownback (R-KS) and Larry Craig (R-ID) tried to insert an exemption rider into the conference report of the agricultural appropriations bill. The rider would have exempted livestock operations from EPCRA's monitoring and reporting requirements, dramatically reducing the potential regulatory burden and financial exposure that ongoing EPCRA litigation poses to AFOs. The exemption language, adopted by the Senate conferees on October 25th, was rejected by the conference committee in their October 27th report.

Quantitative Results. Political and judicial wrangling aside, a great deal of money and effort has been expended in recent years to estimate the rate at which NH_3 is emitted from cattle feedyards and dairies. During the last three years, for example, a consortium of state and federal researchers in Texas and Kansas has been using a wide variety of methods to estimate NH_3 emissions from cattle feedyards, including:

- Direct, surface-isolation methods (flux chambers, wind tunnels)

- Mass-balance methods (input/output, nutrient-ratio, other)
- Box models
- Dispersion modeling methods (backward Lagrangian stochastic, Gaussian, other)

Although convergence is not *by itself* sufficient to ensure that a value or range of values is accurate, independent estimates of the emission flux that do not converge on an arbitrarily narrow range of values will all be suspect. A brief synthesis of as-yet-unpublished data from our consortium project indicates that the annualized NH_3 flux (expressed as N) from a cattle feedyard is likely to be somewhere between 40 and 50% of the total N fed to the animals, a range that reflects a reasonable convergence of 4 independent methods (Todd and Cole, 2005). In general, surface-isolation methods like wind tunnels and flux chambers yield flux estimates substantially lower than 40% of fed N (Mutlu et al., 2005).

Abatement

Abatement methods for NH_3 emissions tend to fall in the following, broad categories:

- Maintaining acidic pH
- In-situ oxidation
- Inhibition of urease
- Segregation of solid manure from urine
- Recapture and recycling
- Feeding strategies to increase N use efficiency

To date, representative methods within all of those approaches have been validated at the benchtop and pilot scales, but commercial-scale adoption faces prohibitive logistical and financial hurdles (e. g., Parker et al., 2005; Cole et al., 2005).

Particulate Matter

Emissions

Variability of Estimates. Estimating PM emissions from spatially extensive, spatially and temporally variable, weather-dependent sources like feedyards and dairies is complicated, and estimates have varied widely since the 1970s (Peters and Blackwood, 1977; Parnell, 1994; Grelinger and Lapp, 1996; Parnell et al, 1999; Price, 2004). However, it is clear from recent, quasi-real-time monitoring that diurnal variations in downwind concentrations of PM (Auvermann, 2005; Parnell et al., 2005) result from interactions between time-varying emission rates and diurnal changes in the stability of the atmospheric boundary layer.

Particle-Size Distribution. Any environmental sample of PM will contain particles having a wide range of sizes and shapes. Agricultural dusts, which result from mechanical actions like crushing and grinding, generally consist of much larger particles than urban aerosols, which are dominated by combustion products. One simple way to express the particle-size distribution (PSD) of agricultural dust is the ratio of sub-10-micron particle (PM_{10}) mass to the total aerosol mass. This ratio is known as the PM_{10}/TSP ratio, and Sweeten et al. (1988) found that its value in feedyard dust varies between 0.19 and 0.40, depending on the type of sampler used. Recent, quasi-real-time concentration data by Goodrich and Parnell (2006) have shown that the PM_{10}/TSP ratio in feedyard dust increases immediately after a rainfall event and then decreases rapidly to the typical value as the feedyard dries out. Similar data by Auvermann (2006) confirm that qualitative result, although his measured PM_{10}/TSP ratios (0.40-0.55) are numerically higher than those measured by Goodrich and Parnell (2006) (0.15-0.25). The explanation for the discrepancy between the PM_{10}/TSP ratios measured by Goodrich and Parnell (2006) and Auvermann (2006) is still a matter of conjecture, but it appears to be an artifact of (a) the well documented, upward bias in PM_{10} measurements when EPA-standard, size-selective inlets are deployed in samplers measuring coarse aerosols (Buser et al., 2003), (b) significant performance differences between real-time and time-averaged monitors (Wanjura et al., 2005) and (c) differences between *post-hoc* (e. g., Coulter Counter PSD analysis) and inertial methods of measuring the PM_{10}/TSP ratio.

Visibility. Fugitive PM from open-lot AFOs may reduce visibility on nearby roadways and railways, posing a safety risk to motorists and pedestrians. The *extinction efficiency* of AFO aerosols is the relative change in visibility for a unit change in mass concentration. Recent work by Moon et al. (2005) has shown that extinction efficiency of AFO aerosols is roughly equivalent to that of "coarse particles" (Malm, 1999) during dry weather. Because feedyard and dairy aerosols tend to absorb water vapor from the air when relative humidity (RH) is high (the particles are thus described as *hygroscopic*), their extinction efficiency depends strongly on RH and increases with increasing RH.

<u>Abatement</u>

General Considerations. Open-lot dairies and cattle feedyards are large, ground-level area sources of PM, their production areas having a footprint of anywhere from 100 to 400+ square feet per head of capacity (ft^2/hd). To reduce PM emissions at the source, Auvermann et al. (2000) have recommended that operators of these facilities consider increasing the frequency with which they harvest the uncompacted manure from corral surfaces. Although retrofitting an older dairy or feedyard with solid-set sprinkler systems is often prohibitively expensive, open-lot dairies may use water trucks to good advantage for dust control by applying water to the corral surface while the cows are in the milking parlor (Cassel et al., 2003).

Manure Accumulation. Manure accumulation rates in dairy and feedyard corrals vary with the digestibility of the ration, animal spacing and dry-matter intake. For beef cattle receiving feed with a digestibility of 85%, assuming uniform distribution of manure on the corral and an animal spacing of 150 ft^2/hd, manure accumulation may exceed 3 inches per year. Total mixed rations (TMR) for lactating dairy cows are less digestible than feedyard rations (~60% or less), but open-lot areas and dry-matter intake tend to be greater, as well. A reasonable estimate of manure accumulation in a dairy drylot with 400 ft^2/hd and dry-matter intake of 50 lb/d would be >6 inches per year.

Manure-Harvesting Recommendations. Cattle feedyard managers typically instruct machinery operators to scrape any given pen once or twice a year, usually after a load of cattle is shipped to slaughter. Benchtop experiments by Razote et al. (2006) confirmed the conjecture by

Auvermann et al. (2000) that the dust-emission potential of a cattle feedyard surface increases with increasing manure depth. That result justifies the manure-harvesting recommendation, but the law of diminishing returns applies strongly to the economics of manure-harvesting operations. If the manure-accumulation rate is 3 in/yr, the average depth of manure in the corrals would be about 1.5", 0.75", 0.5" and 0.38" for 1, 2, 3 and 4 manure-harvesting operations per year, respectively. The marginal reductions in dust potential for the 4th and subsequent manure-harvesting operations in a 12-month period are probably not detectable in practice, which argues for a maximum of 4 operations per year. (If manure is not distributed uniformly across the pens, the 4th and 5th harvesting operation per year may help by removing locally deep accumulations.) Because there are usually about 2-2.2 turns of cattle through a feedyard per year, manure-harvesting operations will need to be conducted occasionally with cattle in the pens. In the case of open-lot dairies, the movement of cattle to and from the milking parlor provides ample opportunity for frequent manure harvesting, in which case the main limitations are fuel, labor costs and the mechanical strength of the subsoils.

Water Application. Direct water application to suppress dust on the cattle feedyard is an effective but expensive option, and where water resources are limited, efficiency is at a premium. Using small weighing lysimeters loaded with compacted soil and manure, Marek et al. (2004) measured daily evaporation rates from simulated feedyard surfaces and determined that the consumptive use of irrigated crops is a poor predictor of feedyard evaporative losses and that water application rates for dust control need to be about 0.15-0.25" per day during most of the dust season, with higher rates during August and September.

Razote et al. (2006) also confirmed that manure harvesting and water application have a synergistic effect on the dust potential of a corral surface. When the uncompacted manure layer significantly exceeds the depth to which applied water will penetrate, the water is essentially wasted; conversely, when dry manure is harvested and used to build mounds to improve wintertime drainage, water must be added to the manure to improve compaction and ensure that hoof action does not redistribute the uncompacted material.

Summary

Recent investments in air quality research, both public and private, are beginning to show returns for the dairy and beef industries across the U. S. The major airborne constituents of regulatory concern nationwide have been reduced to two: ammonia (NH_3) and particulate matter (PM). Constituents of regional and local concern include reactive volatile organic compounds (RVOC) in California, where RVOC are implicated in ground-level ozone formation; odorants of various kinds at the state and local level; and hydrogen sulfide (H_2S) in densely populated areas where neighbors are located immediately across the property line from facilities where manure and/or wastewater are stored under anaerobic conditions. Bioaerosols are attracting greater attention, mainly in the context of biosecurity and zoonotic disease. Innovative measures to reduce emission rates and downwind concentrations of PM and gases from feedyards and dairies have been proposed and validated, but broad implementation will require financial incentives and will generally increase the use of scarce water and fuel resources.

References

Auvermann, B. W. 2006. Unpublished data.

Auvermann, B. W., D. B. Parker and J. M. Sweeten. 2000. Manure harvesting frequency: the feedyard manager's #1 dust-control option in a summer drought. College Station, TX: Texas Cooperative Extension. Bulletin E-52.

Buser, M. D., C. B. Parnell, Jr., B. W. Shaw and R. E. Lacey. 2003. Particulate Matter Sampler Errors Due To The Interaction Of Particle Size and Sampler Performance Characteristics: PM_{10} and $PM_{2.5}$ Ambient Air Samplers. Presented at the Third International Conference on Air Pollution from Agricultural Operations, Raleigh/Durham, NC, October 12-15.

Cassel, T., D. Meyer, E. Tooman and B.W. Auvermann. 2003. Effects of sprinkling of pens to reduce particulate emissions and subsequent efforts in ammonia emissions from open-lot dairy facilities. Presented at the International Symposium of Gaseous & Odour Emissions from Animal Production Facilities, Horsens, Jutland, Denmark, June 1-4.

Cole, N.A., R. N. Clark, R. W. Todd, C. R. Richardson, A. Gueye, L. W. Greene and K. McBride. 2005. Influence of Dietary Crude Protein Concentration and Source on Potential Ammonia Emissions from Beef Cattle Manure. *Journal of Animal Science*. 83:722-731.

Goodrich, B. and C. B. Parnell, Jr. 2006. Unpublished data.

Grelinger, M. A. and T. Lapp. 1996. An evaluation of published emission factors for cattle feedlots. Proceedings of the First International Conference on Air Pollution from Agricultural Operations, Kansas City, MO, February 7-9.

Malm, W. C. 1999. *Introduction to Visibility*. Ft. Collins, CO: Cooperative Institute for Research in the Atmosphere. 70 pp.

Marek, G., T. H. Marek, K. Heflin and B. W. Auvermann. 2004. Determination of Feedyard Evaporation Using Weighing Lysimeters. Presented at the 2004 ASAE/CSAE Annual International Meeting, August 1-4, 2004, Ottawa, Ontario, Canada. Paper No. 04-4014.

Moon, S., B. W. Auvermann and W. J. Rogers. 2005. Open-Path Transmissometry To Determine Atmospheric Extinction Efficiency Associated with Feedyard Dust. Presented at the Annual Conference of the Air & Waste Management Association, Minneapolis, MN, June 20-25.

Mutlu, A., S. Mukhtar, S. Capareda, C. Boriack, R. Lacey, B. Shaw and C. B. Parnell, Jr.. Summer Ammonia Emission Rates From Free-Stall and Open-Lot Dairies in Central Texas. Presented at the 2005 ASAE/CSAE Annual International Meeting, Tampa, FL, July 17-20. Paper No. 05-4037.

Parker, D.B., S. Pandrangi, L. W. Greene, L. K. Almas, N. A. Cole, M. B. Rhoades and J. A. Koziel. 2005. Rate and Frequency of Urease Inhibitor Application for Minimizing Ammonia Emissions from Beef Cattle Feedyards. *Transactions of the ASAE* 48(2):787-793.

Parnell, C. B. Jr., B. W. Shaw and B. W. Auvermann. 1999. Agricultural Air Quality Fine Particle Project - Task 1: Livestock - Feedlot PM Emission Factors and Emissions Inventory Estimates. Final project report to the Texas Natural Resource Conservation Commission. Department of Agricultural Engineering, Texas A&M University, College Station, TX.

Parnell, S. 1994. Dispersion Modeling for Prediction of Emission Factors for Cattle Feedyards. Unpublished Master of Science Thesis, Department of Agricultural Engineering, Texas A&M University, College Station, TX.

Peters, J. A. and T. R. Blackwood. 1977. Source assessment: beef cattle feedlots. Special report to the EPA Office of Research and Development, Research Triangle Park, NC. EPA-600/2-77-107.

Price, J. E. 2004. Back-Calculating Emission Rates for Ammonia and Particulate Matter from Area Sources Using Dispersion Modeling. Unpublished M.S. Thesis, Biological and Agricultural Engineering Department, Texas A&M University, College Station, TX.

Razote, E. B., R. G. Maghirang, B. Z. Predicala, J. P. Murphy, B. W. Auvermann, J. P. Harner and W. L. Hargrove. 2006. Dust emission potential of cattle feedlots as affected by feedlot surface characteristics. *Transactions of the ASAE* (edition pending).

Sweeten, J. M., C. B. Parnell, Jr., R. S. Etheredge and D. Osborne. 1988. Dust emissions in cattle feedlots. *Food Animal Practice* 4(3):557-578.

Todd, R. and N. A. Cole. 2005. Unpublished data. USDA-Agricultural Research Service, Bushland, TX.

Todd, R.W., N. A. Cole, L. A. Harper, T. K. Flesch and B. H. Baek. 2005. Ammonia and Gaseous Nitrogen Emissions from a Commercial Beef Cattle Feedyard Estimated Using the Flux-Gradient Method and N:P Ratio Analysis. Proceedings of "State of the Science: Animal Manure and Waste Management," January 4-7, 2005, San Antonio, TX.

Todd, R. T., N. A. Cole and R. N. Clark. 2006. Effect of Crude Protein in Beef Cattle Diets on Ammonia Emissions from Artificial Feedyard Surface. *Journal of Environmental Quality* (edition pending).

Vasconcelos, J. T., L. W. Greene, N. A. Cole, F. T. McCollum and J. C. Silva. 2004. Effects of Phase Feeding of Protein on Performance, Blood Urea Nitrogen, and Carcass Characteristics of Finishing Beef Cattle. *Journal of Animal Science Supplement* 82(1):63-64.

Wanjura, J. D., C. B. Parnell, Jr., B. W. Shaw and R. E. Lacey. 2004. A Protocol for Determining a Fugitive Dust Emission Factor from a Ground Level Area Source. Presented at the 2004 ASAE/CSAE Annual International Meeting, August 1-4, 2004, Ottawa, Ontario, Canada. Paper No. 04-4018.

Wanjura, J., C. B. Parnell, B. W. Shaw, R. E. Lacey, S. C. Capareda and L. B. Hamm. 2005. Comparison of Continuous Monitor (TEOM) vs. Gravimetric Sampler Particulate Matter Concentrations. Paper presented at the 2005 ASAE/CSAE Annual International Meeting, Tampa, FL, July 17-20. Paper No. 05-4048.