Ammonia Emissions from Poultry Production

2022

DELMARVA LAND AND LITTER COLLABORATIVE

Introduction

Delmarva Land and Litter Collaborative (DLLC) brings together representatives from the poultry industry, farming, regulatory agencies, academia, and environmental groups in a collaborative and mission-driven manner. We understand that the complex challenges facing the integration of food production, environmental protection, rural economies, and communities cannot be solved by single-faceted approaches. DLLC members prioritized learning more about ammonia emissions resulting from poultry production. This paper provides an overview of what we have learned from experts in academia, modeling, regulatory, and non-profit organizations.

Chesapeake Bay Program (CBP) modeling shows that nitrogen coming from all manure sources (livestock and poultry) has been relatively constant or slightly decreasing from 1985 to 2019. During that period, airborne nitrogen from other sources, such as fossil fuel use, has been reduced so that the share of total nitrogen entering the Chesapeake from manure sources has increased[1]. DLLC members are looking for practical solutions to reduce ammonia emissions from poultry production to improve watershed health, and to ensure that the CBP accounts for ammonia reduction practices that have been put in place by the poultry industry. What follows is a summary of the science, production management practices affecting ammonia, and what we identified as key gaps in our collective understanding.

Ammonia and the Nitrogen Cycle

Nitrogen (N) exists as an inert gas (N_2), and biologically reactive forms such as ammonium (NH_4^+), ammonia (NH_3), nitrite (NO_2^-) and nitrate (NO_3^-). N_2 gas comprises 78% of the earth's atmosphere and is converted to biologically active forms by either an industrial process, lightning bolts, or microorganisms in a process called nitrogen fixation. Many of the nitrogen-fixing microorganisms are associated with the roots of legumes including crops like soybeans and alfalfa. After 1913, industrial nitrogen fixation using the high-temperature Haber-Bosch process laid the foundation for the production of inorganic nitrogen fertilizers.

Ammonia and ammonium are the most biologically reactive forms of nitrogen, and it is important to understand the difference between them. The balance between ammonium and ammonia depends on pH. In acidic conditions, (below pH 7), ammonium (NH_4^+) dominates. Under basic/alkaline conditions, ammonia (NH_3) dominates. Ammonia exists as a volatile gas and is the form that is of concern in poultry litter emissions. High concentrations of ammonia in bird housing can negatively impact bird health, and ammonia that leaves poultry houses can be deposited on terrestrial and aquatic ecosystems. Typical tests for nitrogen concentrations do not distinguish between ammonia and ammonium and a single reporting number as ammonia nitrogen is typically presented and used to track environmental nitrogen processes.

Nitrogen (N), phosphorus (P), and potassium (K) are the most limiting nutrients for plants, represented by the three numbers on fertilizer bags indicating the content of N:P:K (by percent) in the fertilizer. Plants and animals use nitrogen to make proteins and other molecules required by living things. However, excess nitrogen in the form of ammonia can be toxic in high concentrations. For this reason, mammals convert excess ammonia into urea that is excreted in the urine. Birds and reptiles convert excess ammonia into uric acid, which is excreted as part of the animal or bird's feces.

Nitrite (NO_2^-) and nitrate (NO_3^-) are oxidized forms of nitrogen, commonly referred to (along with NO) as NOx. NOx can be formed by microbes oxidizing ammonia and by the combustion of fuels like coal, fuel oil, gasoline, and biomass. Some microbes can convert NOx molecules back to ammonium, and others can convert the reactive nitrogen molecules back to N_2 gas. This is the reverse of nitrogen fixation called denitrification, which is generally how reactive nitrogen is removed from the system. Both ammonium and nitrate are plant-available, meaning they can be utilized by plants to support growth. Inorganic fertilizers typically consist of ammonium or nitrate-based nitrogen. However, plants must reduce the nitrate to ammonium to make proteins.

Manures from animals and birds contain ammonium, nitrate, phosphorus, and potassium in addition to a myriad of micronutrients and, therefore, make a good organic fertilizer. However, only a small portion of the nitrogen in poultry litter is plant-available - estimated to be 18%[2]. Most of the nitrogen in animal manure is bound in organic molecules. Microbes use organic matter as a food source and excrete ammonium as a waste product, a process called mineralization. Because this process takes time, manure can act as a slow-release fertilizer.

In the past, fertilizer use of manure focused on the nitrogen content, resulting in some cases of over-application of manure phosphorus and other nutrients. Over-application of nutrients increases the risk of loss to air and water resources. Farmers who follow nutrient management plans, that prescribe recommended nutrient application rates based on soil tests and plant needs, help avoid the over-application of nutrients from either manure or inorganic fertilizers and reduce environmental impacts.

Back to the Birds

The white part of bird and reptile droppings is the uric acid they make to excrete excess nitrogen produced internally from digesting their food. When birds are grown in concentrated flocks, like barnyards and poultry houses, the droppings can build up significantly and are useful as manure fertilizer. The amount of uric acid produced is dependent on feed conversion efficiency, or how much of the feed nitrogen ends up as nitrogen in the bird and how much is excreted as excess. An increase in nitrogen assimilation into bird mass (increased growth efficiency) translates into a decrease in the amount of nitrogen excreted as uric acid. Increased growth efficiency has been a goal of the poultry industry, improving bird yield on feed and thereby reducing waste nitrogen.

Controlling Ammonia Inside Poultry Houses

High levels of gaseous ammonia are unhealthy for birds, especially for young chicks. High ammonia concentrations in poultry housing can damage the respiratory system of birds, increasing the risk for disease. Because of the negative health impacts of ammonia on birds in poultry houses, managing ammonia levels in houses is a priority for poultry growers. The industry has been researching and implementing ammonia reduction methods for decades. The biggest reductions in ammonia generation have come from genetic and feed enhancements to increase growth efficiency, reducing the amount of uric acid in manure, and management of moisture and litter pH.

Microbes in the house bedding convert uric acid to ammonium, but they require water to do so. A litter pH of more than 7 is responsible for ammonium conversion to volatile ammonia and its loss as gas from poultry manure. When pH is less than 7, ammonium (NH_4^+) is the more abundant form. Consequently, NH_3 emission can be inhibited by acidifiers that lower manure pH and reduce the conversion of ammonium to ammonia. Litter treatments such as Sodium bisulfate (Poultry Litter Treatment- PLT®), Poultry Guard, and alum (A7, 3^+, or Liquid Alum) bind water and reduce the pH of the litter, inhibiting bacteria from converting uric acid to ammonium and conversion of ammonium to ammonia gas. Various techniques are used to limit moisture in the litter to prevent the conversion of uric acid to ammonium. These techniques include efficient waterers that limit spillage and ventilation that is also used to keep moisture and in-house ammonia levels down.

Preventing ammonia at the source is best because ventilation is very expensive and is not adequate to control the conversion of uric acid to ammonia. Ventilation management reduces the concentration of ammonia in a poultry house by increasing airflow to both keep the litter dry and remove ammonia from the in-house air. The ability of airflow to dry litter depends on reducing in-house air humidity which is affected by the incoming air temperature and humidity. In warm humid conditions, it is more difficult to keep litter dry with ventilation, which increases the emission of ammonia from the production houses. House ventilation management requires a lot of energy and is a balance between energy used to warm outside air brought in when it is cooler for ammonia reduction by moisture management, and the energy used to move larger volumes of air to displace ammonia when outside conditions are warm and moist[3].

With better moisture control that limits caking or crusting of litter, many growers are reusing litter for multiple flocks (built-up litter). After a flock is out, litter is windrowed and composted to build up heat and kill pathogens, and respread prior to the arrival of a new flock. Composting and recycling litter results in a higher ammonium content of the litter from multiple flocks compared to single-use litter. While composting has economic and bird health benefits, the practice does increase ammonia emissions from litter by 30-80% compared to undisturbed litter[4,5]. Regardless of treatment, emissions between flocks are still lower than with birds in houses[5].

What Happens When Ammonia Leaves Poultry Houses?

The emission of ammonia from poultry houses shifts our focus from risks to birds to risks to the environment. Ammonia (NH_3) is released as volatile gas, and ammonium can be released into the atmosphere in association with coarse and fine particulate matter. While volatile ammonia and coarse particulate matter are typically not transported long distances, fine particulate matter can be transported hundreds of miles from the emissions source[6]. Ammonium deposited on the land is readily taken up by plants, soil microbes, and algae in surface waters as an essential element until it exceeds their needs. Because nitrogen is a limiting nutrient for plant growth, an overabundance can result in excess phytoplankton growth in aquatic ecosystems. While some ammonium is essential for ecosystem health, too much ammonia can create imbalances. From an ecosystem perspective, the overabundance of ammonium, nitrate, and phosphorous from all human activity is of concern.

Ammonia emissions from agriculture are temperature dependent, and thus show a seasonal cycle over a national scale. The seasonality of ammonia emissions is depicted in Figure 1 with very low atmospheric concentrations in the winter months and higher concentrations in the warmest months of the year (Figure 1). Once released into the atmosphere, ammonia concentrations near the ground decrease exponentially (rapidly) with distance from poultry houses (Figure 2). The decrease of ammonia with distance is a result of both deposition to land and dilution into the air.

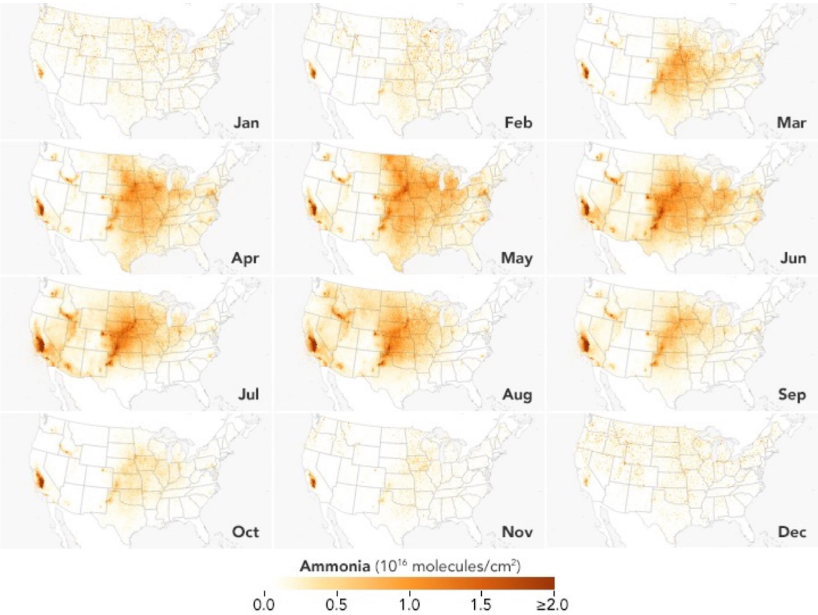

Figure 1. NASA Earth Observatory: https://earthobservatory.nasa.gov/images/144351/the-seasonal-rhythms-of-ammonia

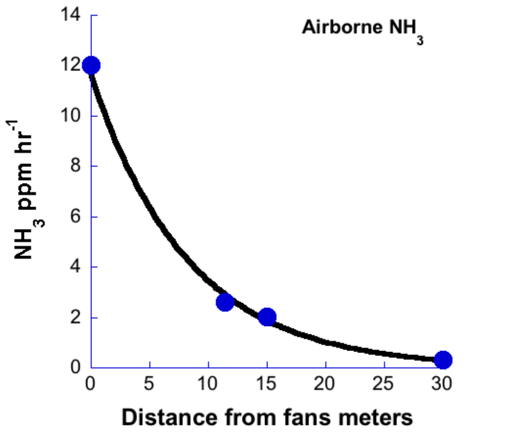

Figure 2. Exponential loss of airborne ammonia with distance from poultry house fans. Trees were planted at 11.4 and 15 m and the samples taken within the trees. The equation for this curve is NH_3 ppm $hr^{-1} = 11.576 * e^{(-0.121 * \text{meters distance})}$. Data and curve extracted from Adrizl et al. (2008)[10].

Vegetative buffers planted to intercept air leaving poultry houses via exhaust fans increase the deposition of dust and ammonia[7]. Research has shown that vegetative buffers can reduce ammonia from poultry operations by about a quarter, while dispersing about a third of the remainder to reduce near-field effects[8]. Others have found that not all plants are equally good for vegetative buffers. For example, *Padus virginiana* outperformed *Padus maackii*, Winged *Euonymus*, *Malus spectabilis*, and *Acer saccharum marsh* in reducing the downwind transport of particulate matter[9]. Other work

found that while spruce and hybrid willow are effective traps for dust and associated odors, poplar, hybrid willow, and Streamco willow are appropriate species to absorb aerial NH_3[10]. Forest canopy length, height, and leaf area have been shown to be factors related to capturing ammonia from the air[11], and thus the natural forested areas of the Delmarva downwind of poultry operations may also act as a sink for agricultural ammonia emissions.

Monitoring Ammonia

Ammonia air emissions are being monitored at various sites by a partnership between the Maryland Department of the Environment (MDE), Keith Campbell Foundation for the Environment, the Delmarva Chicken Association (DCA), and the University of Maryland Eastern Shore. Data from these sites are available on the MDE webpage and have been summarized for April 2020 through March 2021 in a report[12]. One of these stations is located in downtown Baltimore (Oldtown), and three are on the Eastern Shore with different land use and poultry house densities. The Horn Point station represents background for the Delmarva without nearby poultry operations and has the lowest values over time (Figure 3) and the lowest average values (Figure 4). The city of Cambridge and its wastewater treatment plant are 4 miles to the east, and there are at least 23 houses within 10

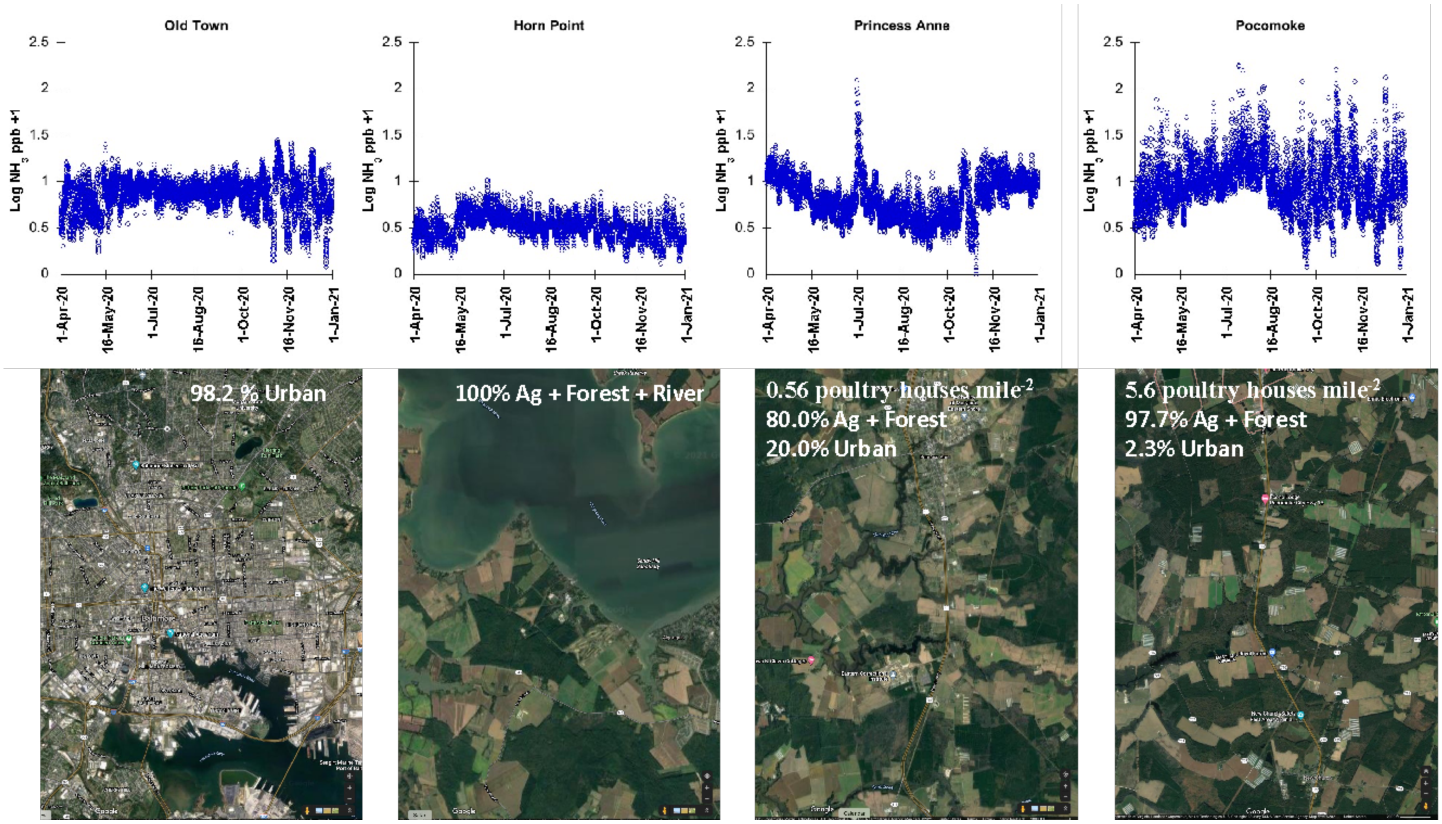

Figure 3. Graphics produced with data from: https://mde.maryland.gov/programs/Air/AirQualityMonitoring/Pages/Lower-Eastern-Shore-Monitoring-Project.aspx. Houses per square mile were calculated from the number of houses in a 2-mile radius around the sensors.

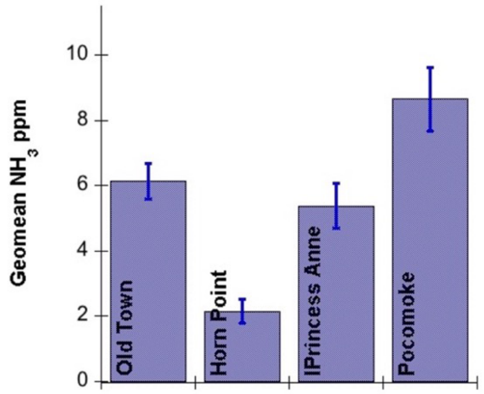

Figure 4. Averages of ammonia air concentrations recorded by Maryland Department of the Environment (MDE) at the stations in Figure 3. Averages are of log transformed data. Data obtained from: https://mde.maryland.gov/programs/Air/AirQualityMonitoring/Pages/Lower-Eastern-Shore-Monitoring-Project.aspx.

miles distance to the south and south southeast of this station, with the closest poultry operations at about a 6 miles distance. After having established background data for atmospheric ammonia on the Delmarva, the operation of this station has been discontinued to focus the resources elsewhere. An additional monitoring station is planned for near Preston, MD.

While it is not possible to distinguish nearby urban from poultry influences for Princess Anne and Pocomoke City, the input from poultry operations is clearly seen with the increase in poultry house density from Horn Point to Pocomoke City (Figures 3 and 4). The spike seen in the Princess Anne data is from the application of anhydrous ammonia (liquid fertilizer) on nearby corn fields[12]. The low values at Horn Point (2.15 ± 0.36 ppb) suggest these emissions from poultry may be atmospherically localized. The average for the Princess Anne station (5.36 ± 0.69 ppb) is slightly lower than the average for the Baltimore urban station (6.13 ± 0.54 ppb). The data from Pocomoke City (8.64 ± 0.96 ppb) has a higher average and is more variable than the relatively steady emission of ammonia from the urban station at Old Town (6.13 ± 0.54 ppb). None of the recorded values are close to thresholds for human health concern[13].

Although conflated with urban and other agricultural sources, the Princess Anne and Pocomoke data indicate a signature of poultry house ammonia emissions. Horn Point represents background for Delmarva and indicates a limited distribution of airborne poultry ammonia. Urban and other sources of ammonia in the Chesapeake Bay watershed (coal and oil combustion in power plants and vehicles, wastewater treatment plants, and other sources) may be more consistent spatially and seasonally as seen in the data for Old Town Baltimore (Figure 3). More sampling stations would add data points to better calibrate air emissions to the density of houses and birds (Figure 5) to improve estimates of losses of ammonia to the environment from poultry production. To date, there has been a lack of context provided for ammonia coming from poultry operations, and there are unanswered questions in understanding the magnitude of the problem.

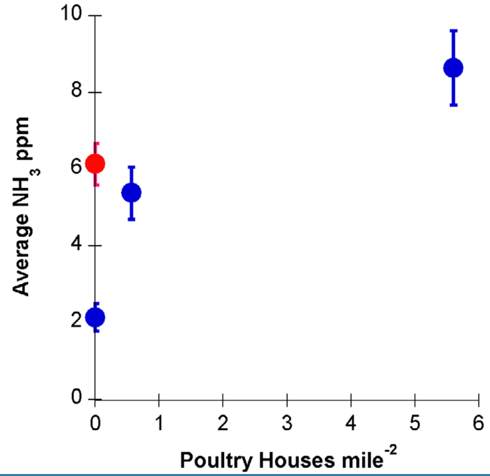

Figure 5. Average ammonia concentrations from air sensors relative to the density of poultry houses within a 2-mile radius of the sampling sites. The red dot is the average from the Old Town Baltimore sampling location. Data for the graphics from: https://mde.maryland.gov/programs/Air/AirQualityMonitoring/Pages/Lower-Eastern-Shore-Monitoring-Project.aspx.

Improving Understanding of Ammonia Fate and Transport

The Delmarva Land and Litter Collaborative hosted a series of webinars in 2021 to increase members' understanding of poultry-related ammonia emissions and management. Presenters included Brian Fairchild (University of Georgia), Hong Li (University of Delaware), Paul Patterson (Penn State University), Kyoung Ro (USDA-ARS), Viney P. Aneja (North Carolina State University), Jesse Bash (EPA National Exposure Research Lab) and Gary Shenk (US Geological Survey). These experts summarized the impact of ammonia on the environment, the technologies and practices used to control ammonia emissions and the science of estimating ammonia deposition for guiding management decisions. Following is a summary of findings and questions raised during the sessions.

Defining and modeling ammonia emissions and their fate is a complex problem.

- Ammonia deposition is increasing in the bay watershed and nationally.
- Overall agricultural ammonia emissions tend to follow a seasonal pattern, with greater emissions in the warm seasons. Urban sources and atmospheric deposition from fossil fuel combustion and wastewater treatment plants may be more consistent.
- Ammonia leaving chicken houses as emissions to the air may reach the Chesapeake Bay, Delaware Bay, or the Atlantic Ocean or may be retained in the terrestrial landscape.
- The EPA National Exposure Research Lab uses atmospheric modeling to simulate ammonia deposition resulting from all sources, including poultry production. Model estimates can be validated by air measurement networks and satellite observations.
- The CBP uses watershed modeling to track the nitrogen delivery from all sources, including ammonia deposition, under the Chesapeake Total Maximum Daily Load (TMDL) for water quality. The model estimates ammonia losses to soil storage, volatilization, and uptake by biota.

How can modeling be improved?

- Ammonia production from poultry increases with the size of birds as they grow, with most ammonia emissions in the last 2 weeks. Do current estimates of ammonia per bird match current bird growth efficiency?
- Poultry houses are not continually full of birds. Built-up (reused) litter emissions are never zero, but less during inter-flock and early flock periods when birds are absent or small.
- Loss of nitrogen as ammonia from litter is dependent on litter management practices. Have current litter amendment use, litter storage, transport, and application practices been incorporated?
- Ammonia emissions have limited geographic dispersal. Where is ammonia deposited relative to sources? What fraction goes to Delaware Bay and the Atlantic Ocean vs the Chesapeake Bay?
- Ammonia emissions are adsorbed (onto) and absorbed (into) planted vegetative buffers. How much of poultry emissions are being captured by vegetative buffers? Recognizing that terrestrial nitrogen is subject to transport over time, are vegetative buffers incorporated into the model?
- Ammonia emissions are absorbed by natural vegetation in forests and wetlands. How much ammonia is incorporated into Delmarva's natural forests, grasslands, swamps, and wetlands and internally recycled, stored, or denitrified to N_2 gas versus ammonia that is transported to surface waters over time?
- Litter nitrogen applied to fields is absorbed by crops and natural vegetation around fields with some loss to groundwater and stormwater runoff. How much litter nitrogen in grains is recycled in the feed that supports poultry production?

Footnotes

[1]Chesapeake Bay Program, 2020. Chesapeake Assessment and Scenario Tool (CAST) Version 2019. Chesapeake Bay Program Office, Last accessed April, 2022.

[2]VA DCR. 2014. *Virginia Nutrient Management Standards and Criteria* (Revised July 2014). Commonwealth of Virginia, Department of Conservation and Recreation Division of Soil and Water Conservation, Richmond, VA. 117 pp.

[3]Czarick, M. University of Georgia. *Presentation at the National meeting on Poultry Health, Processing, and Live Production*, Sept 27-29 2021.

[4]Lian, Y., K. VanDevender, G. Tom Tabler. 2010. Ammonia emissions from downtime litter management in broiler housing. *Int. Symp. on Air Quality and Manure Mgmt. for Ag.Conf. Proc.*, 13-16 September 2010, Dallas, Texas. 711P0510cd.(doi:10.13031/2013.32661)

[5]Ro, KS, PA Moore Jr., AA Szogi, and PD Millner. 2017. Ammonia and nitrous oxide emissions from broiler houses with downtime windrowed litter. *J. Enviorn. Qual.* 46:498-504.

[6]Asman, W.H., M. Sutton, J.K. Schjøing. 1998. Ammonia: Emission, atmospheric transport and deposition. *New Phytol.* 139, 27-48.

[7]Malone, B. Personal communication at the National meeting on Poultry Health, Processing, and Live Production, Sept 27-29 2021.

[8]Ro, KS, H Li, CJ Hapeman, LA Harper, TK Flesch, PM Downey, LL McConnell, A Torrents, and Q Yao. 2018. Enhanced dispersion and removal of ammonia emitted from a poultry house with a vegetative environmental buffer. *Agriculture* 8 46-57.

[9]Guo, L, S Ma, D Zhao, and B Zhao. 2019. Experimental Investigation of Vegetative Environment Buffers in Reducing Particulate Matters Emitted from Ventilated Poultry House. *Journal of the Air & Waste Management Association* 69: 934-943. DOI:10.1080/10962247.2019.1598518

[10]Adrizal, A, PH Patterson, RM Bates, CAB Myers, GP Martin, RL Shockley, M van der Grinten, DA Anderson, and JR Thompson. 2008. Vegetative buffers for fan emissions from poultry farms: 2. Ammonia, dust, and foliar nitrogen. *Journal of Environmental Science and Health Part B* 43:96-103.

[11]Beasley, WK, B Loubet, CF Braban, D Famulari, MR Theobald, S Ris, DS Reay, and MA Sutton. 2014. Modeling agro-forestry scenarios for ammonia abatement in the landscape. *Environ. Res. Let.* 9: 125001 (15 pp). doi:10.1088/1748-9326/9/12/125001

[12]MDE. 2022. Lower eastern Shore Air Quality Monitoring Project April 2020 – March 2021. *Ambient Air Monitoring Program Air and Radiation Administration, Maryland Department of the Environment.* https://mde.maryland.gov/programs/Air/AirQualityMonitoring/Pages/Lower-Eastern-Shore-Monitoring-Project.aspx

[13]James Boyle, MDE presentation at the National Meeting on Poultry Health, Processing, and Live Production, Sept 27-29 2021.