Scrubbers remove NH₃ gas and PM from poultry exhaust plumes this way: air passes through a scrubbing liquid (water and diluted acids) and reacts with the liquid, forming ammonium salts, effectively “scrubbing” the air. Scrubbers can be a powerful tool in reducing both dust and odor; however, many available scrubbers are expensive. This study used a scrubber that offered effective remediation at lower cost. Further, the ammonium salt precipitate from scrubbers was returned to crop productions as a captured fertilizer.

VEBs are strategic “hedgerows” composed of trees, shrubs, and, more recently, grasses planted near the exhaust fans of poultry houses to capture NH₃, VOCs, and PM. Recent studies demonstrate that 1) VEB plants near fans take up more NH₃ than plants located further away from fans, 2) VEB plants can capture particles, and 3) that odors were decreased downwind of VEBs. Scientists found additional emissions reductions, through the contribution of grasses, especially Miscanthus and Panicum (switchgrass) species, if added to VEBs. These grasses are useful because of their perennial habit and low cost, relative to some shrubs and trees.

Innovative Approaches to Capture Nitrogen and Air Pollutant Emissions from Poultry Operations

Project Summary: Implementing best management practices (BMPs) and developing new BMPs or best-available technologies to mitigate AFO air emissions has been a focus for the USDA NRCS under the Conservation Innovation Grants and EQIP programs and many Land-Grant University projects. Development of cost-effective air emission mitigation and assessing the effectiveness of these technologies is urgently needed to improve our environmental performance and to help producers address increasing Federal regulatory pressures. Poultry producers and scientists worked together to use vegetative environmental buffers (VEBs) and acid scrubbers to capture ammonia (NH₃), volatile organic compounds (VOCs), and particulate matter (PM). This project deployed and tested emerging scientific approaches to managing airborne poultry house emissions that used VEBs and scrubbers in tandem to achieve environmental goals in a cost-effective, low-impact manner. Three broilers farms in Delaware and Pennsylvania were used to quantify the reduction efficiency of VEBs on downwind gaseous and PM concentrations and emissions in warm seasons. Time-integrated PM, NH₃, and VOCs samples were collected at multiple downwind locations and heights of the three sites with and without VEBs. Results showed 20% or higher PM and NH₃ concentration and emission reductions by the VEBs. VEB also showed promising potential in decreasing the ozone formation potential (OFP). Data also showed that grass VEBs had negligible adverse effect on fan performance at two times of fan diameters. Low-cost two-stage acid scrubbers designed by USDA ARS were installed on minimum exhaust fans and evaluated over an 18-month period on four farms in Arkansas, Delaware, and Pennsylvania. The capturing efficiency of the scrubber on NH₃ was up to 44% with daily to weekly maintenances. More frequent maintenances can significantly improve the capturing efficiency.
Pollutant emissions to the atmosphere commonly derive from nonpoint sources that are extended in space. Such sources may contain area, volume, line, or a combination of emission types. Currently, point measurements, often combined with models, are the primary means by which atmospheric emission rates are estimated from extended sources. Point measurement arrays often lack in spatial and temporal resolution and accuracy. In recent years, lidar has supplemented point measurements in agricultural research by sampling spatial ensembles nearly instantaneously. Here, a methodology using backscatter data from an elastic scanning lidar is presented to estimate emission rates from extended sources. To demonstrate the approach, a known amount of particulate matter was released upwind of a vegetative environmental buffer, a barrier designed to intercept emissions from animal production facilities. The emission rate was estimated downwind of the buffer, and the buffer capture efficiency (percentage of particles captured) was calculated. Efficiencies ranged from 21% to 74% and agree with the ranges previously published. Instantaneous lidar scans showed periodic lofting well above the VEB, but when scans were averaged over several hours, the plumes appeared Gaussian. This paper documents experimental evidence quantifying the capture efficiency of a VEB. It also establishes an experimental framework for future studies on the efficacy of various emissions mitigation strategies. The methodology introduced here is demonstrated by estimating the efficiency of a vegetative buffer, but it can also be applied to any extended emission source for which point samples are inadequate, such as roads, animal feedlots, and cotton gin operations. It can also be applied to any pollutant for which a lidar system is configured, such as particulate matter, carbon dioxide, and ammonia.

Lidar has been used to obtain spatially resolved estimates of particulate mass fluxes and emission rates downwind of AFOs. With a scanning lidar, we create range–height indicator (RHI) scans downwind of an emission source, approximately perpendicular to the wind direction. These scans contain backscatter data at various ranges from the lidar and at various heights above the surface. The backscatter data are inverted to show spatially resolved mass concentrations in a two-dimensional vertical slice of the atmosphere. These concentrations are multiplied by perpendicular wind speeds to produce mass flux and emission rate maps, which are spatially integrated to determine the total emission rate.

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The capture efficiencies ranged between 21 and 74% amongst six runs. The performance of the VEB varied based on time of day. The VEB captured a larger fraction of particulates during the night and a smaller fraction during the day. Five of the six runs were performed during the day, while only one was performed at night. Since sampling times were non-uniformly distributed amongst a 24-h period, the average diurnal capture efficiency was not determined. The result is consistent with the large range (35–68%) of experimental results reported in the literature.

Capture efficiency varied throughout the day. The capture efficiencies for all runs, both slices, are shown as black lines spanning the entire run duration. The six runs were carried out over 24–26 June 2013, and all results throughout the time period are combined into one time series in this figure. Shading indicates night time.
Several variables influenced the capture efficiency, including the wind speed and direction, turbulence intensity, and release distance. Turbulence has been shown to dominate transport from AFOs to the surrounding atmosphere, and it is likely that turbulence contributed to the VEB performance. Daytime surface heating creates density inversions in the surface layer, and vertical motion results, enhancing turbulence production within the VEB. Conversely, nighttime surface cooling generates a stably stratified layer which degrades turbulence. We characterize the turbulence within the VEB as mechanically-dominated and enhanced or suppressed by buoyancy. The VEB least effectively removed particulates during the daytime runs (capture efficiency = 47±14%). The VEB was most effective during the nighttime run (capture efficiency = 73±1.5%). The VEB therefore performed best during times with less turbulence. Since the wind speed was well-correlated with turbulence, the VEB also performed best during times of slower wind speeds.

VEB design considerations include height, thickness, porosity, tree species, and orientation. We varied the release distance from the VEB in an effort to determine a recommended distance VEBs should be installed from the facility. Due to the varying nature of atmospheric conditions throughout the day, it is appropriate to contrast results obtained at the same time of day under similar atmospheric conditions. A further distance between the discharge tunnel and the VEB resulted in a higher (8–9%) VEB capture efficiency under the same atmospheric conditions.
Effectiveness of Vegetative Environmental Buffers in Mitigating Ammonia, VOCs, and PM from Poultry Operations

With field campaigns on a commercial farm, VEBs showed downwind concentration reduction for major air pollutants emitted from the poultry house. By comparing the field-observed and model-predicted downwind concentration of VEBs, the reduction efficiencies of VEBs were 17%, 21%, 25%, and 25% for TSP, PM10, PM2.5, and NH3, respectively. TSP, PM10, and PM2.5 emissions and reduction were statistically correlated. PM2.5 and NH3 emissions were strongly correlated as NH3 knowingly contributes to secondary PM2.5. The efficiencies of VEBs on PM2.5 and NH3 were also strongly correlated. The result also showed that the main VOCs emitted poultry operation included methanol, ethanol, and acetone, of which are also found to have the largest ozone formation potential (OFP). A substantial decrease in the OFP for methanol was observed from the poultry house equipped with VEBs. These results suggest that VEBs can provide control on the VOCs emitted from poultry production.

Three sampling campaigns were conducted in July 2014, September 2014 and August 2015 (Campaign 1, 2, and 3). Each campaigns held five daytime and 5 nighttime experiments to collect air samples over a sampling period around 12 hours. 3-m and 10-m sampling towers with various sampling heights were deployed perpendicularly to the primary tunnel fan at the distances of 2, 6, and 20m from the fan. The sampling heights were 1, 2, 3, 4.5, 7.25, and 10 m. A background sampler was deployed at approximately 150 m away northwest from the tunnel fans. Meteorological conditions during the sampling period were recorded at each sampling point.

Total suspended particulate samples were collected using the low-volume TSP sampler heads designed and manufactured by Texas A&M / USDA-ARS and Teflon filters. TSP concentrations were obtained using a microbalance in the environmental chamber. All filters were conditioned in an environmental chamber (21 ± 2°C; 35 ± 5% RH) for 48 hours prior to gravimetric analyses. PM10 and PM2.5 concentrations were obtained by particle size distribution analyses of the TSP filter samples.

Passive diffusive samplers (PDS) were deployed to measure the time-averaged ammonia concentrations. The PDS sampler used microporous polyethylene impregnated with phosphoric acid as cartridges to adsorb ammonia. Only the gaseous-phase ammonia were absorbed due to the diffusive layer of PDS, which functioned as a shield to eliminate any interferences from particulate matters. Samplers were quantified by UV spectrometry at wavelength $\lambda = 635$ nm as indophenol.

US EPA Method TO-15 was used to collect VOCs with using 1-L amber glass canisters coupled with a filtered restrictor to afford 2-hr integrated air samples. The filter of the restrictor ensured that particulates were not collected. All canisters were cleaned and evacuated for 20 cycles and reached a final evacuation of -1.04 atm using a canister cleaner automatic system.

A modified small-scale Gaussian plume model (Yang & Yao, 2017) was used in this study to estimate air dispersion from a horizontal source without VEBs.
(continued)

**Downwind PM Reduction**

Based on statistical analysis, TSP and PM2.5 measurements showed no statistical significant difference at Camp 1, but had a statistical significant difference at Camps 2 and 3; the diurnal and nocturnal PM10 measurements had a statistical significant difference in all the campaigns. Day time and night time PM emissions were analyzed separately.

Both observed and predicted PM concentrations inversely related with heights at 2m distance location in front of fans (T1). PM does not disperse to the higher samplers (> 3 m) within this short distance. For PM concentrations inside the VEB (T2), it showed similar trend as in front of the fans. The concentrations decrease with increased heights for sampling points higher than 3 m. It also showed a slight increase in TSP concentrations with increased height around ground level due to the particulate dispersion.

Ground-level observed data at T2 were all higher than predicted data. It was possibly caused by trapping effect of VEBs on PM and PM accumulation at T2. Ground-level observed PM concentrations behind the VEB (T3) were all noticeably lower than predicted values. The reduction efficiencies of VEB were 17%, 21%, and 25% for TSP, PM10 and PM2.5 respectively.

![Tukey box-plots of observed and predicted TSP concentrations at different sampling points.](image)

**Downwind NH₃ Reduction**

Day and night NH₃ concentration data from each campaign was combined for analysis due to the difference between diurnal and nocturnal data groups is not significant for all three campaigns (p-value > 0.05). NH₃ concentrations decreased with increased heights at T1 and T2. The NH₃ concentration decline was more noticeable at the higher sampling points (4.5m, 7.25m, and 10m). The NH₃ concentrations at higher levels (< 3 m) was slightly larger at T2 than at T1. T2 was set up inside the VEB. It was possible because the NH₃ dispersed higher with longer distance, while VEB trapped the NH₃ due to its sticky property that readily adsorbed onto almost all surfaces.

T3 had significantly lower observed concentration levels for all three campaigns at ground level (< 3 m). NH₃ reduction efficiency of VEB was 15% to 25% during the daytime and 13% to 25% during the nighttime by comparing field-observed and model-predicted data from all campaigns. This result showed the high potential of reducing NH₃ downwind concentration from the poultry houses by VEB.

![Tukey box-plots of diurnal and nocturnal VEB reduction efficiency on NH₃ from field-observed and model-predicted data.](image)
Innovative, Seasonal Technology for Managing Poultry House Emissions

Spring 2017

(continued)

Downwind VOCs Reduction

Nine VOCs in the C2 – C6 molecular weight range (molar mass < 90 g mol⁻¹), including propene, methanol, acetone, ethanol, acetonitrile, hexane, propanol, butanol, butanal, were quantitatively analyzed in the laboratory. These VOCs could contribute to ground-level ozone formation in the area. Additionally, odor problems could also be introduced into the neighborhood by these VOC emissions from the poultry houses. Data indicated that methanol, acetone, and ethanol were originated from the broiler houses. Carbon sulfide, dimethyl sulfide, dimethyl disulfide, and hexanal were emitted from the poultry houses. However, poultry houses were not considered the primary emission sources for VOCs such as acetonitrile, propanol, butanol, hexane, and propene, as well as nonanal and toluene. Results showed that the downwind ground-level (2-m height) methanol concentration was reduced by 23% during the day and 27% during the night with VEBs. VEBs showed potential in mitigating methanol in exhaust air and reducing ozone formation potential (OFP). Various factors including temperature, relative humidity, wind conditions could have impacts to the results.

Assessment of Fan Performances Affected by Vegetative Environmental Buffers

- Airflow was reduced less than 3% when grass VEBs were located one fan diameter downstream.
- Grass VEBs had negligible adverse effect on fan performance at 2x fan diameters downstream.
- Grass VEBs benefit the performances of tunnel fans under commercial operations by mitigating the wind effect on the fans in direct winds.

VEBs plants near fans take up more air pollutants than plants located further away from exhaust fans. We anticipate additional emissions reductions, through the contribution of grasses, especially Miscanthus and Panicum (switchgrass) species, if added to VEBs. These grasses can tolerate the harsh environment when they are planted close to poultry house exhaust fans, especially the tunnel fans. These grasses are useful because of their perennial habit and low cost, relative to some shrubs and trees. However there are some concerns on tunnel fan performances affected by grass type VEBs.

Field fan performance tests were conducted to determine the effect of distance of grass VEBs on the performance of tunnel fans. Tunnel fans of poultry houses with grass VEBs were evaluated on fan performances by using fan assessment numeration system (FANS).
Effectiveness of Acid Scrubber on Particulate Matters and Ammonia Emissions from Broiler Houses

Recent research has shown that over half of nitrogen excreted by chickens is lost into the atmosphere via ammonia volatilization before the litter is removed from poultry houses. Large quantities of particulate matter and volatile organic compounds (VOCs) are also emitted from animal rearing facilities. An acid scrubber has been developed for capturing ammonia, VOCs and dust from air exhausted from poultry operations. The objectives of this project were conducting full-scale testing of the scrubber under field conditions through different seasons and growth cycle and evaluating the cost, practicality and efficacy of the scrubber for scrubbing ammonia. The year-long average efficiency of ammonia removal by the scrubbers was up to 44%, depending on the maintenance schedule, air flow rate, fan control strategies, and litter management. This technology could potentially result in the capture of a large fraction of the N lost from AFOs, while simultaneously reducing emissions of bacteria, dust, and odors, which would improve the social, economic, and environmental sustainability of poultry production.

Development of cost-effective air emission mitigation and assessing the effectiveness of these technologies is urgently needed to improve our environmental performance and to help producers address increasing regulatory pressures. Scrubbers have been shown to be a powerful tool in reducing ammonia (NH₃), dust and odor emissions. An affordable two-stage acid scrubber was developed by USDA ARS for treating exhaust air and can easily be installed onto the exhaust fans of existing poultry facilities. A field monitoring was conducted to evaluate the efficiency of the acid scrubber under field conditions on three broiler farms, two located in Delaware (DE) and one located in Pennsylvania (PA).

The two-stage scrubbers were installed on the minimum fans of three farms that were using different practices and settings. One farm used 36” minimum fans and reused existing litter throughout the project while an organic farm used a 36” minimum fan, but used new bedding materials for every flock. The third scrubber was installed on a research farm with a 24” minimum fan and used litter. Sodium bisulfate was used as the acid agent. Ammonia concentration and airflow rate through each fan were continuously measured. Scrubber liquid samples were analyzed to calculate the efficiency of each scrubber. Acid, water and electricity consumption of each scrubber were recorded over multiple flocks and seasons.

The mean NH₃ capturing efficiencies of the three scrubbers for the three sites were 40, 44 and 14 %, respectively. The low efficiency (11%) of one scrubber was due to high NH3 emission rate and inadequate acid solution in the scrubber (the solution at this site was checked and replaced weekly whereas the solution at the other two sites were checked daily). For every kg NH3 captured, the average water, sodium bisulfate and electricity consumption at the three sites were 0.23 m³, 15.10 kg and 43.74 kWh, respectively.

Table 1. Acid, water, and energy consumption of scrubbers

<table>
<thead>
<tr>
<th>Site</th>
<th>Fan, in</th>
<th>NaHSO₄, kg</th>
<th>Water, m³</th>
<th>Electricity, kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE-1</td>
<td>36&quot;</td>
<td>6.86</td>
<td>0.17</td>
<td>20.3</td>
</tr>
<tr>
<td>DE-2</td>
<td>24&quot;</td>
<td>15.72</td>
<td>0.33</td>
<td>72.8</td>
</tr>
<tr>
<td>PA</td>
<td>36&quot;</td>
<td>22.72</td>
<td>0.19</td>
<td>88.5*</td>
</tr>
<tr>
<td>Ave</td>
<td>--</td>
<td>15.10</td>
<td>0.23</td>
<td>60.53</td>
</tr>
</tbody>
</table>

* Estimated by pump rated power and running time

Based on the field experiences of running the three scrubbers, several recommendations are suggested: 1) increase fan run time to compensate for air flow loss due to high pressure drop, 2) add insulation on drain valves, 3) heat fresh water line and add a heater in pump boxes, 4) clean dust scrubber at least twice per flock for houses with used litter, 5) replace acid solution more frequently toward end of the flock for best performance, 6) add a storage tank for spent liquid if the growers do not have crops or pasture to apply to, and 7) add an automatic acid dosing system to reduce labor requirement and improve scrubber performance.
Outreach, Selected Presentations, and Peer Reviewed Publications

Timely dissemination of information to poultry producers and allied industries, government agencies, and the concerned public was a key component of this project. The project team continues to foster stakeholder engagement in the project, and educate them about air and water quality problems for poultry operations and potential innovative conservation and management strategies to combat those problems. Furthermore, the project team provided many opportunities for public entities, producers, and integrators to directly and indirectly take action—and responsibility—for the control of air emissions and capturing reactive nitrogen. Outreach and technology transfer methods utilized and/or developed during this reporting period include formal presentation, meeting with stakeholders, and project website.

UMD and USDA-ARS team members prepared an outreach flyer to introduce the project and its goals to producers, regulators, and extension agents at the annual Delaware Ag Week. Harrington, Delaware. 1/13/2013


Sutterfield, D. 2014. Design and development of an isokinetic multi-point particulate matter air sampling system. ASABE annual international meeting. 7/14/2014


Sutterfield, D. 2014. Velocity profile development for a poultry facility acid scrubber. ASABE annual international meeting. 7/16/2014

Li, H. 2014. Effectiveness of Vegetative Environmental Buffers on Trace-Gas Plume Concentration. ASABE annual international meeting. 7/16/2014

Yao, Q. 2014. Utilizing vegetative environmental buffers to mitigate ammonia and particulate matter emissions from poultry houses. 248th ACS National Meeting and Exposition. 8/11/2014


Yao, Q. 2015. Assessing the effectiveness of vegetative environmental buffers in mitigating air pollutants from poultry houses. Chesapeake-Potomac Regional Chapter (CPRC) SETAC 2015 Annual Spring Meeting. 4/25/2015


Zhang, C. 2015. Using wet scrubber to capture ammonia emission from broiler houses ASABE annual meeting. 7/27/2015


Craig, C. 2016. Alternative wet scrubber design for removing particulate matter from poultry house ventilation fans. ASABE annual international meeting. 7/19/2016

Zhang, C. 2016. Using wet scrubber to reduce ammonia emission from broiler house. ASABE annual international meeting. 7/20/2016

Buser, M. 2016. Mitigating ammonia and volatile organic compounds (VOCs) emissions from poultry houses using vegetative environmental buffers. ASABE annual international meeting. 7/20/2016

Buser, M. 2015. Evaluating the effectiveness of VEBs in mitigating particulate matter emissions from poultry houses. ASABE annual international meeting. 7/20/2016

Li, H. 2016. Assessment of fan performances affected by vegetative environmental buffers. ASABE annual international meeting. 7/20/2016


Who We Are

Hong Li, University of Delaware, led this USDA Conservation Innovation Grant (CIG). Li has considerable experience in large scale, multi-year monitoring projects to measure gaseous pollutant and particulate emissions from AFOs, especially poultry operations. He coordinated the team, and oversaw fabrication of the mobile monitoring system, managed the collection of NH₃ concentration measurements, and the calibration of site ventilation fans. His university colleagues, Eric Benson, Stephen Collier, and Bill Brown, assisted with measurements, especially at DE sites, where distribution modeling was an important activity.

Mike Buser, Oklahoma State University, is an expert in the measurement of PM emissions from agricultural operations and will oversee the installation, collection, and analysis of PM samples. For 10 years, he has worked with Greg Holt, USDA Agriculture Research Service - Lubbock, TX, analyzing PM samples. Buser designed and crafted new sampling equipment for this project and related studies.

Alba Torrents, and Cathleen Hapeman and Laura McConnell, USDA Agriculture Research Service - Beltsville, MD, are experts in environmental sampling and analysis techniques for gaseous and particulate pollutants, and have conducted many joint studies for over 20 years. They were responsible for carrying out collection and analysis of VOC samples and worked with other team members to coordinate sampling and data analysis, especially at the PA and DE sites.

Philip Moore, USDA Agriculture Research Service - Fayetteville, AK, is an expert in nutrient management and the control of emissions from poultry production; he holds a patent in scrubber technology. He led scrubber construction/installation, and coordinated with team members to evaluate scrubber effectiveness.

Paul Patterson and Greg Martin, Pennsylvania State University, study the impact of VEBs for NH₃, PM, odor, and virus mitigation both in experiments and on commercial poultry farms. They helped manage the PA study site, providing expertise and leadership in outreach and through extension training materials. Marybeth Shea, environmental consultant at the University of Maryland, developed stakeholder communication documents.

Project leaders also participated in outreach activities and conducted field days. We plan to work with the Poultry Association, the American Society for Agricultural and Biological Engineers, and Cooperative Extension programs, as well as shared our work at poultry industry meetings.

Other Key Team Members:

Qi Yao, University of Delaware
William Willis, University of Iowa
William Eichinger, University of Iowa
John Prueger, USDA ARS
Kyoung Ro, USDA ARS
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About this work: Supported by a 2012 USDA Conservation Innovation Grant (CIG), this work was part of the National Resource Conservation Service’s voluntary program intended to stimulate the development and adoption of innovative conservation approaches and technologies while leveraging Federal investment in environmental enhancement and protection, in conjunction with agricultural production. Under CIG, Environmental Quality Incentives Program funds were used to award competitive grants to non-Federal governmental or nongovernmental organizations, Tribes, or individuals. 

Grant Title: Innovative Approaches to Capture Nitrogen and Air Pollutant Emissions from Poultry Operations