2008

Vegetative buffers for fan emissions from poultry farms: 2. ammonia, dust and foliar nitrogen

A. Adrizal
University of Jambi

P. H. Patterson
Pennsylvania State University

R. M. Hulet
Pennsylvania State University

R. M. Bates
Pennsylvania State University

C. A.B. Myers
Pennsylvania State University

See next page for additional authors

Vegetative buffers for fan emissions from poultry farms: 2. ammonia, dust and foliar nitrogen

Abstract

This study evaluated the potential of trees planted around commercial poultry farms to trap ammonia (NH_3) and dust or particulate matter (PM). Norway spruce, Spike hybrid poplar, hybrid willow, and Streamco purpleosier willow were planted on five commercial farms from 2003 to 2004. Plant foliage was sampled in front of the exhaust fans and at a control distance away from the fans on one turkey, two laying hen, and two broiler chicken farms between June and July 2006. Samples were analyzed for dry matter (DM), nitrogen (N), and PM content. In addition, NH_3concentrations were measured downwind of the exhaust fans among the trees and at a control distance using NH_3 passive dosi–tubes. Foliage samples were taken and analyzed separately based on plant species. The two layer farms had both spruce and poplar plantings whereas the two broiler farms had hybrid willow and Streamco willow plantings which allowed sampling and species comparisons with the effect of plant location (control vs. fan). The results showed that NH_3 concentration h^{-1} was reduced by distance from housing fans ($P \leq 0.0001$), especially between 0 m (12.01 ppm), 11.4 m (2.59 ppm), 15 m (2.03 ppm), and 30 m (0.31 ppm). Foliar N of plants near the fans was greater than those sampled away from the fans for poplar (3.87 vs. 2.56%; $P \leq 0.0005$) and hybrid willow (3.41 vs. 3.02%; $P \leq 0.05$). The trends for foliar N in spruce (1.91 vs. 1.77%; $P = 0.26$) and Streamco willow (3.85 vs. 3.33; $P = 0.07$) were not significant. Pooling results of the four plant species indicated greater N concentration from foliage sampled near the fans than of that away from the fans (3.27 vs. 2.67%; $P \leq 0.0001$). Foliar DM concentration was not affected by plant location, and when pooled the foliar DM of the four plant species near the fans was 51.3% in comparison with 48.5% at a control distance. There was a significant effect of plant location on foliar N and DM on the two layer farms with greater N and DM adjacent to fans than at a control distance (2.95 vs. 2.15% N and 45.4 vs. 38.2% DM, respectively). There were also significant plant species effects on foliar N and DM with poplar retaining greater N (3.22 vs. 1.88%) and DM (43.7 vs. 39.9%) than spruce. The interaction of location by species ($P \leq 0.005$) indicated that poplar was more responsive in terms of foliar N, but less responsive for DM than spruce. The effect of location and species on foliar N and DM were not clear among the two willow species on the broiler farms. Plant location had no effect on plant foliar PM weight, but plant species significantly influenced the ability of the plant foliage to trap PM with spruce and hybrid willow showing greater potential than poplar and Streamco willow for $PM_{2.5}$(0.0054, 0.0054, 0.0005, and 0.0016 mg cm^{-2}; $P \leq 0.05$) and total PM (0.0309, 0.0102, 0.0038, and 0.0046 mg cm^{-2}, respectively; $P \leq 0.001$). Spruce trapped more dust compared to the other three species (hybrid willow, poplar, and Streamco willow) for PM_{10} (0.0248 vs. 0.0036 mg cm^{-2}; $P \leq 0.0001$) and $PM_{>10}$ (0.0033 vs. 0.0003 mg cm^{-2}; $P = 0.052$). This study indicates that poplar, hybrid willow, and Streamco willow are appropriate species to absorb poultry house aerial NH_3–N, whereas spruce and hybrid willow are effective traps for dust and its associated odors.

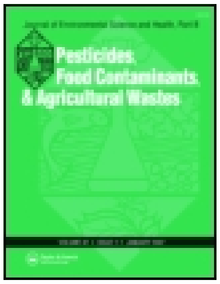
Keywords

Picea abies, Populus deltoides & times, Populus nigra, Salix matsudana ×, Salix alba, Salix purpurea, leaf nitrogen, leaf dry matter, commercial poultry farms, ammonia, particulate matter

Disciplines

Natural Resources Management and Policy

Authors
A. Adrizal, P. H. Patterson, R. M. Hulet, R. M. Bates, C. A.B. Myers, G. P. Martin, R. L. Shockey, M. van der Grinten, D. A. Anderson, and Janette R. Thompson



Journal of Environmental Science and Health, Part B: Pesticides, Food Contaminants, and Agricultural Wastes
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lesb20

Vegetative buffers for fan emissions from poultry farms: 2. ammonia, dust and foliar nitrogen

A. Adrizal [a], P. H. Patterson [b], R. M. Hulet [b], R. M. Bates [c], C. A.B. Myers [d], G. P. Martin [e], R. L. Shockey [f], M. van der Grinten [g], D. A. Anderson [h] & J. R. Thompson [h]

[a] Faculty of Animal Husbandry, University of Jambi, Jambi, Indonesia
[b] Department of Poultry Science, Pennsylvania State University, University Park, Pennsylvania, USA
[c] Department of Horticulture, Pennsylvania State University, University Park, Pennsylvania, USA
[d] Pennsylvania State University Cooperative Extension-Livestock, Leesport, Pennsylvania, USA
[e] Pennsylvania State University Cooperative Extension-Poultry, Lancaster, Pennsylvania, USA
[f] United States Department of Agriculture (USDA)-National Resources Conservation Service (NRCS), Harrisburg, Pennsylvania, USA
[g] United States Department of Agriculture (USDA)-National Resources Conservation Station (NRCS), Big Flats Plant Materials Center, Corning, New York, USA
[h] Department of Natural Resource Ecology and Management, Iowa State University, Ames, Iowa, USA

Published online: 26 Dec 2007.

To cite this article: A. Adrizal , P. H. Patterson , R. M. Hulet , R. M. Bates , C. A.B. Myers , G. P. Martin , R. L. Shockey , M. van der Grinten , D. A. Anderson & J. R. Thompson (2008): Vegetative buffers for fan emissions from poultry farms: 2. ammonia, dust and foliar nitrogen, Journal of Environmental Science and Health, Part B: Pesticides, Food Contaminants, and Agricultural Wastes, 43:1, 96-103

To link to this article: http://dx.doi.org/10.1080/03601230701735078

Journal of Environmental Science and Health Part B (2008) **43**, 96–103

ISSN: 0360-1234 (Print); 1532-4109 (Online)
DOI: 10.1080/03601230701735078

Vegetative buffers for fan emissions from poultry farms: 2. ammonia, dust and foliar nitrogen

A. ADRIZAL[1], P.H. PATTERSON[2], R.M. HULET[2], R.M. BATES[3], C.A.B. MYERS[4], G.P. MARTIN[5], R.L. SHOCKEY[6], M. VAN DER GRINTEN[7], D.A. ANDERSON[8] and J.R. THOMPSON[8]

[1]*Faculty of Animal Husbandry, University of Jambi, Jambi, Indonesia*
[2]*Department of Poultry Science, Pennsylvania State University, University Park, Pennsylvania, USA*
[3]*Department of Horticulture, Pennsylvania State University, University Park, Pennsylvania, USA*
[4]*Pennsylvania State University Cooperative Extension-Livestock, Leesport, Pennsylvania, USA*
[5]*Pennsylvania State University Cooperative Extension-Poultry, Lancaster, Pennsylvania, USA*
[6]*United States Department of Agriculture (USDA)-National Resources Conservation Service (NRCS), Harrisburg, Pennsylvania, USA*
[7]*United States Department of Agriculture (USDA)-National Resources Conservation Station (NRCS), Big Flats Plant Materials Center, Corning, New York, USA*
[8]*Department of Natural Resource Ecology and Management, Iowa State University, Ames, Iowa, USA*

This study evaluated the potential of trees planted around commercial poultry farms to trap ammonia (NH_3) and dust or particulate matter (PM). Norway spruce, Spike hybrid poplar, hybrid willow, and Streamco purpleosier willow were planted on five commercial farms from 2003 to 2004. Plant foliage was sampled in front of the exhaust fans and at a control distance away from the fans on one turkey, two laying hen, and two broiler chicken farms between June and July 2006. Samples were analyzed for dry matter (DM), nitrogen (N), and PM content. In addition, NH_3 concentrations were measured downwind of the exhaust fans among the trees and at a control distance using NH_3 passive dosi–tubes. Foliage samples were taken and analyzed separately based on plant species. The two layer farms had both spruce and poplar plantings whereas the two broiler farms had hybrid willow and Streamco willow plantings which allowed sampling and species comparisons with the effect of plant location (control vs. fan). The results showed that NH_3 concentration h^{-1} was reduced by distance from housing fans ($P \leq 0.0001$), especially between 0 m (12.01 ppm), 11.4 m (2.59 ppm), 15 m (2.03 ppm), and 30 m (0.31 ppm). Foliar N of plants near the fans was greater than those sampled away from the fans for poplar (3.87 vs. 2.56%; $P \leq 0.0005$) and hybrid willow (3.41 vs. 3.02%; $P \leq 0.05$). The trends for foliar N in spruce (1.91 vs. 1.77%; $P = 0.26$) and Streamco willow (3.85 vs. 3.33; $P = 0.07$) were not significant. Pooling results of the four plant species indicated greater N concentration from foliage sampled near the fans than of that away from the fans (3.27 vs. 2.67%; $P \leq 0.0001$). Foliar DM concentration was not affected by plant location, and when pooled the foliar DM of the four plant species near the fans was 51.3% in comparison with 48.5% at a control distance. There was a significant effect of plant location on foliar N and DM on the two layer farms with greater N and DM adjacent to fans than at a control distance (2.95 vs. 2.15% N and 45.4 vs. 38.2% DM, respectively). There were also significant plant species effects on foliar N and DM with poplar retaining greater N (3.22 vs. 1.88%) and DM (43.7 vs. 39.9%) than spruce. The interaction of location by species ($P \leq 0.005$) indicated that poplar was more responsive in terms of foliar N, but less responsive for DM than spruce. The effect of location and species on foliar N and DM were not clear among the two willow species on the broiler farms. Plant location had no effect on plant foliar PM weight, but plant species significantly influenced the ability of the plant foliage to trap PM with spruce and hybrid willow showing greater potential than poplar and Streamco willow for $PM_{2.5}$(0.0054, 0.0054, 0.0005, and 0.0016 mg cm^{-2}; $P \leq 0.05$) and total PM (0.0309, 0.0102, 0.0038, and 0.0046 mg cm^{-2}, respectively; $P \leq 0.001$). Spruce trapped more dust compared to the other three species (hybrid willow, poplar, and Streamco willow) for PM_{10} (0.0248 vs. 0.0036 mg cm^{-2}; $P \leq 0.0001$) and $PM_{>10}$ (0.0033 vs. 0.0003 mg cm^{-2}; $P = 0.052$). This study indicates that poplar, hybrid willow, and Streamco willow are appropriate species to absorb poultry house aerial NH_3–N, whereas spruce and hybrid willow are effective traps for dust and its associated odors.

Keywords: *Picea abies*; *Populus deltoides* × *Populus nigra*; *Salix matsudana* × *Salix alba*; *Salix purpurea*; leaf nitrogen; leaf dry matter; commercial poultry farms; ammonia; particulate matter.

Address correspondence to P.H. Patterson, Department of Poultry Science, Pennsylvania State University, University Park, PA 16802, USA; E-mail: php1@psu.edu
Received May 18, 2007.

Introduction

The increasing scale of confined livestock production to supply more dietary protein has resulted in greater amounts of animal waste, the main precursor of gases and odors on the farm. An earlier study by Jones et al.[1] showed that among several gases [carbon dioxide (CO_2), carbon monoxide (CO), hydrogen sulfide (H_2S), nitrogen dioxide (NO_2), NO_x, methane (CH_4), mercaptan, formaldehyde, hydrocarbons, and ammonia (NH_3)] measured in confinement poultry houses, NH_3 was the major contaminant present at average airborne concentrations of 25 ppm. Dust was the second airborne substance of concern with a total concentration of 4.4 mg m^{-3} and respirable fraction of 0.24 mg m^{-3}, followed by bacteria (1.5×10^5 colony–forming units [cfu] m^{-3}) and fungi (1.0×10^4 cfu m^{-3}).[1] When discharged from exhaust fans of poultry and livestock housing these hazardous emissions may have environmental impacts not only to the ecosystem near the source but also at distances from the source depending on fan speed and climatic conditions.[1−3] Respiratory dysfunction among farm workers from dust and ammonia exposure have been documented by Donham et al.[4] Odors adhering to the farm emissions have also been an increasing nuisance to neighbors.[5] In the atmosphere, aerosol particulates formed by NH_3 with other gases are deposited and may cause further acidification of the land and eutrophication of surface water.[3,6] The United States Environmental Protection Agency (USEPA)[7] in April 2005 issued a revised report listing poultry feeding operations as the major contributor to atmospheric NH_3 from animal agricultural activities. This further suggests that efforts should be explored to mitigate poultry emissions.

Attempts at reducing farm emissions downwind of exhaust fans on livestock farms have included using bio–scrubbers or filter walls,[8−10] which can be relatively costly. Another method that has been increasingly studied is the use of a vegetative shelter belt to capture farm emissions.[11−13] One concern associated with using vegetative shelterbelts is the impact of long term exposure to NH_3 and particulates on plant survival. Foliar injury in Sitka spruce and Scots pine adjacent to livestock farms has been reported by Pitcairn et al.[14] These authors[14] also found natural selection of vegetation downwind of the fans where nitrophillic plant species dominated the landscape. As long as plants were exposed to NH_3 levels below critical concentrations which could cause injury to the foliage,[6] aerial NH_3 may actually stimulate plant growth. The uptake of aerial NH_3 by plant foliage is possible via the glutamine synthetase and glutamate synthase pathways which allows stomata mesophyll cells to incorporate N.[15] However, few studies have reported the potential of plant foliage to trap farm dust or particulate matter (PM), which are EPA[16] regulated emissions (e.g. $PM_{2.5}$ and PM_{10} with aerodynamic diameter of 2.5 and 10 μm, respectively). Malone[12] reported that air speed was reduced by 99%, dust by 50 to 53%, and NH_3 by 29 to 67% at a distance 14.6 m downwind of the tunnel fans of a roaster house beyond three rows of trees including cypress and red cedar. However, this work did not describe specific PM fractions trapped by different plant species.

In the last three years we have measured the capacity of plants to trap NH_3 in environmentally controlled chambers[17] or downwind of the exhaust fans of a layer house on our Penn State University research farm[18,19] with positive results. One study demonstrated the capacity of plants to buffer fan NH_3 emissions and to trap PM at distances from 2.5 to 50 m downwind of the fans.[19] Recently Patterson et al.[20] also measured the effectiveness of plants in capturing airborne NH_3 on commercial poultry farms in Pennsylvania. The study reported here was conducted to validate previous findings and to further evaluate the potential of foliage of different species to reduce aerial NH_3 and trap particulates downwind from commercial poultry farms.

Materials and methods

Study sites

This study included five commercial poultry farms: two broiler farms, two layer farms, and one turkey farm. More than 1,500 plants (Norway spruce [*Picea abies*], Spike hybrid poplar [*Populus deltoides* × *Populus nigra*], hybrid willow [*Salix matsudana* × *Salix alba*], and Streamco purpleosier willow [*Salix purpurea*]) were planted in three to 12 rows downwind of the exhaust fans on these five farms from 2003 to 2004 (Table 1). The distance from the fans to the trees ranged from 11.4 to 17.7 m, and the distance between the rows was approximately 3.0 m. Three replicate foliage samples of the four different species were taken from two to four replicate farms. Foliage samples of Spike hybrid poplar were taken from the two layer farms whereas foliage samples of hybrid willow were taken from the two broiler farms and turkey farm. Foliage samples of Norway spruce were taken from the two layer farms, broiler farm 1, and turkey farm, whereas foliage samples of Streamco purpleosier willow were taken from the two broiler farms and layer farm 2. All the foliage samples were analyzed for N and DM concentration.

Ammonia concentrations were measured using passive dosi–tubes (No. 3D, Gastec Corp., Fukaya 6431, Japan) at 0, 11.4, 15, and 30 m away from the fans among the trees on each farm. The 0 m distance was measured at the fan surface and the 30 m distance was considered the control. Two dosi–tubes were used at each location of NH_3 measurement and each was attached to a 1.5–m high steel post downwind and facing the fans (see Fig. 1, example farm[20]). The tubes were read after 4 to 8 h and concentrations were expressed in ppm h^{-1}.

Table 1. Characteristics of commercial poultry farms and trees

Farm	*House type*	*Birds and houses*	*Farm issues*	*Trees*	*Ventilation and exhaust fans directed at buffer trees*
Broiler 1	litter	50,000/2 houses	Dust, odors and snow load	1 row Norway spruce 1 row hybrid willow 1 row Streamco purpleosier willow	10 at 122 cm and 4 at 91 cm diameter
Broiler 2	litter	21,000/house	Visual screen, snow load, odors and dust	2 rows Norway spruce 1 row hybrid willow 1 row Streamco purpleosier willow	2 at 122 cm and 14 at 91 cm diameter
Layer 1	high-rise	125,000/house	Dust, odors, flies, and visual screen	2 rows Norway spruce 2 rows Spike hybrid poplar	15 at 122 cm and 7 at 91 cm diameter
Layer 2	high-rise	475,000/3 houses	Dust, odors and flies	2 rows Norway spruce 1 row Spike hybrid poplar 1 row Streamco purpleosier willow	14 at 122 cm and 3 at 91 cm diameter
Turkey	litter	40,000/2 houses	Dust, odors, water quality, feathers and truck traffic	2 rows hybrid willow 10 rows Norway spruce	4 at 122 cm diameter and curtain sided

Foliage sampling and analyses

All foliage sampling was conducted in June and July 2006 at two locations, near the fans (11.4 to 17.7 m) and at a control distance away from the fans (the closest was 40 m) (Fig. 1). Foliage samples were sent to the PA State Agricultural Analytical Services Laboratory for total nitrogen (N) and dry weight analysis. The dry matter (DM) of foliage was calculated from the difference of fresh and dry weight over the fresh weight and presented as a percentage value.

Gravimetric analyses

Fresh foliage samples were packed in bottles on ice and shipped overnight to the Department of Natural Resource Ecology and Management Laboratory at Iowa State University for analysis of particulate matter (PM) weight per foliage area (mg cm^{-2}). Branch samples were placed in flasks, and filtered (0.45 μm pore diameter) water was used to rinse the collection bottles and the rinse water was added to the corresponding flask. A 0.02% hepamethyltrisiloxane surfactant solution was created by adding 0.095 mL of the surfactant to each flask and bringing the flask to 500 mL with filtered water. The stoppered flasks were placed in a refrigerator and the samples were allowed to soak for 24 h. The flasks were then placed on a rotational shaker at 200 rpm for 2 h. Each sample was then removed from the flask and rinsed over a funnel using filtered water. The samples were sprayed vigorously, on all sides, allowing the water to collect in the flasks. The resulting solutions were then successively filtered through three pre–weighed, size–selective filters with 1000 μm, 25 μm, and 0.45 μm pore sizes. The filters were dried for 1 h at 105°C, cooled for 15 min, and then re–weighed on a digital microbalance.

Leaf area determination and calculation of particulate load

Leaf area was determined for each vegetative sample. For cylindrical samples, the plant parts were scanned to create digital images. These images were analyzed using Rootedge®software[21] to obtain an area measurement for each sample. For non–cylindrical samples, a LiCor (LI–3100C) meter was used to obtain leaf area measurements. Results are reported as the weight PM captured on each filter per surface area of the vegetative sample (mg cm^{-2}). Particulate matter filtered from 0.45 μm pore filters was designated as $PM_{2.5}$, the PM with aerodynamic equivalent diameters of less than or equal to 2.5 μm. Particulate matter filtered from 25 μm pore filters was designated as PM_{10}, with aerodynamic equivalent diameters of less than or equal to 10 μm. Particulate matter filtered from 1000 μm pore filters was designated as $PM_{>10}$, again with PM aerodynamic equivalent diameters of greater than 10 μm. Total PM was counted as the sum of the three PM categories.

Statistical models

Two mathematical models were used to analyze the data with farms as replicates in each model. The effect of distance from the fans (0, 11.4, 15, and 30 m) on aerial NH_3 concentration was analyzed using Model 1. This model was also applied to analyze the effect of plant location (control vs. fan) on foliar DM and N for each plant species. The effect of plant location on pooled foliar N or DM of the four plant species was tested using a 2 × 4 factorial design (Model 2). Model 2 was also applied with a 2 × 2 factorial design to analyze the effects of plant location (control vs. fan) and species (hybrid willow vs. Streamco purpleosier willow) on foliar DM and N on the two broiler farms. Model 2 was also analyzed using a 2 × 2 factorial design to assess

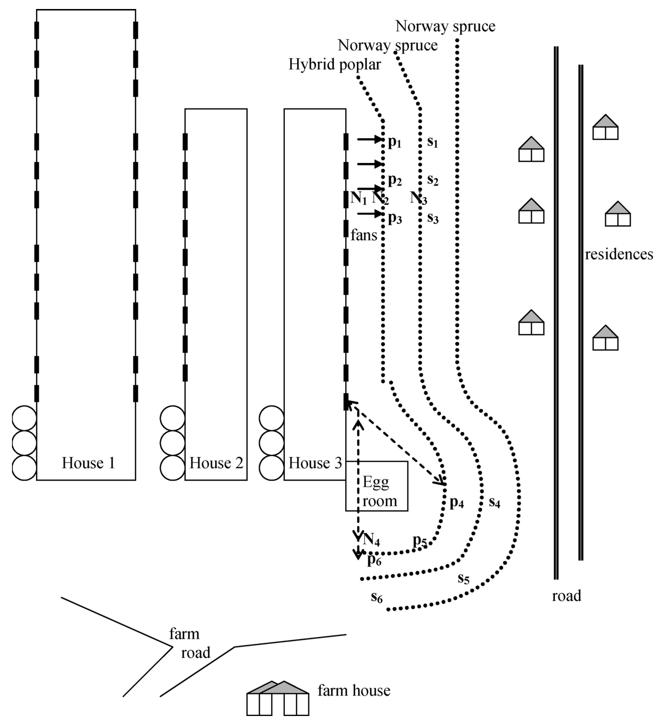


Fig. 1. Example trees planted downwind of the exhaust fans on a layer farm with vegetative filters (adapted from Patterson et al.[20]). $\mathbf{p}_1$–$\mathbf{p}_3$ and $\mathbf{s}_1$–$\mathbf{s}_3$ are sampling locations for Spike hybrid poplar and Norway spruce respectively downwind of the fans whereas $\mathbf{p}_4$–$\mathbf{p}_6$ and $\mathbf{s}_4$–$\mathbf{s}_6$ are sampling locations of the respective species at control distances from the fans. The distance from the fans to $\mathbf{p}_1$–$\mathbf{p}_3$ is 13.5 m and to closest control foliage sampling point ($\mathbf{p}_4$) is 40 m. $\mathbf{N}_1$–$\mathbf{N}_3$ are locations for ammonia measurements at 0, 11.4, and 15 m downwind of the fans whereas $\mathbf{N}_4$ is the location for control ammonia measurement at 30 m away from the fans. The three circles adjacent to the hen houses represent feed bins.

the effects of plant location (control vs. fan) and species (Norway spruce vs. Spike hybrid poplar) on foliar DM and N on the two layer farms. Model 2 was used with a 2 × 5 factorial design to analyze the effect of plant location (control vs. fan) and species (to compare Norway spruce, Spike hybrid poplar, hybrid willow, and Streamco purpleosier willow) on foliar PM. All the data were subjected to a one–way (Model 1) or two–way (Model 2) ANOVA using Proc GLM of SAS followed by the Tukey–Kramer test[22] to distinguish means that showed significance at $P \leq 0.05$. The two mathematical models are described below:

$$X_{ij} = \mu + L_i + \varepsilon_{ij} \qquad \text{(Model 1)}$$
$$X_{ijk} = \mu + L_i + S_j + (L_i \times S_j) + \varepsilon_{ijk} \qquad \text{(Model 2)}$$

where X_{ij} or X_{ijk} is the observed value, μ is the overall mean, L_i is the i–th location (for foliar DM and N analysis of individual plant) or the i–th distance from the fans (for aerial NH_3 analysis), S_j is the j–th species, and ε_{ij} or ε_{ijk} is the residual error for Model 1 and Model 2, respectively.

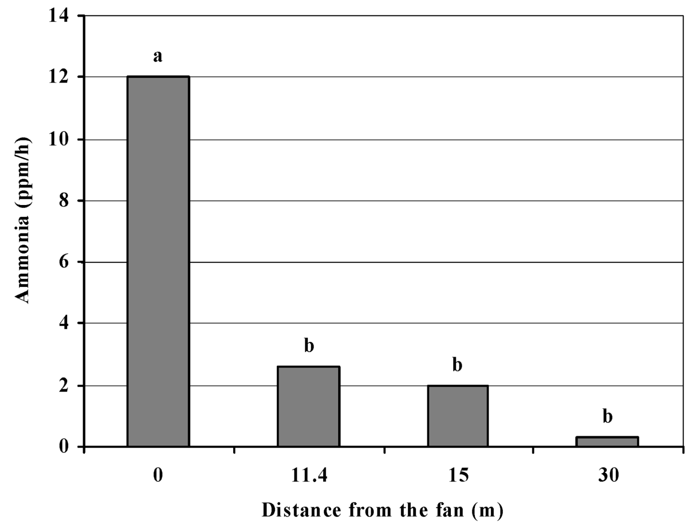


Fig. 2. Aerial ammonia (NH_3) concentrations measured at 0, 11.4, 15, and 30 m downwind of the fans from all five commercial poultry farms (a, b denote significant differences [$P \leq 0.05$]; standard error of the means (SEM) = 0.78).

Results

Airborne NH_3

Ammonia concentration was significantly influenced by distance from the exhaust fans ($P \leq 0.0001$). Ammonia concentration was the highest at 0 m (12.01 ppm h^{-1}), and lower at 11.4 (2.59 ppm h^{-1}), 15 (2.03 ppm h^{-1}), and 30 m (0.31 ppm h^{-1}) (Fig. 2).

Plant foliar N and DM

Foliar N and DM for plant species was pooled from replicate farms (Fig. 3 and 4). Greater concentrations of foliar N were measured for plants sampled near the fans compared with those sampled away from the fans for both Spike hybrid poplar (3.87 vs. 2.56%; $P \leq 0.0005$) and hybrid willow (3.41 vs. 3.02%; $P \leq 0.05$) (Fig. 3). The same numerical trend in foliar N was observed with proximity to the fans for Norway spruce (1.91 vs. 1.77%; $P = 0.26$) and Streamco purpleosier willow (3.85 vs. 3.33; $P = 0.07$). Pooling the data from all five farms and four species showed significantly greater N concentration (22%) for the foliage sampled near the fans compared with foliage from plants at a control distance away from the fans (3.27 vs. 2.67%; $P \leq 0.0001$). However, the effect of plant location (fan vs. control) was not observed for foliar DM with levels of 44.3 vs. 43.0% (Spike hybrid poplar), 62.6 vs. 59.6% (hybrid willow), 44.2 vs. 39.5% (Norway spruce), and 54.2 vs. 51.8% (Streamco purpleosier willow) (Fig. 4). While a similar trend was observed for all species, the pooled results from all farms (51.3 vs. 48.5%) were not significantly different. The impact of plant location and species on foliar DM and N (%) were measured and compared on multiple

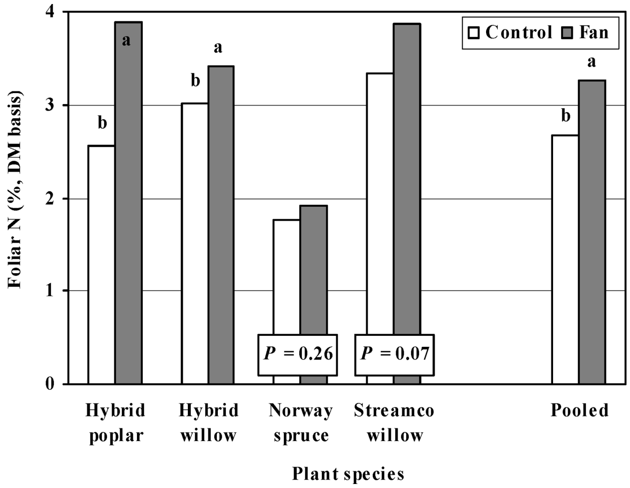


Fig. 3. Foliar nitrogen (N) [%, dry matter (DM) basis] of the plants sampled downwind of the fans in comparison with those sampled at a distance far away from the fans (control). Foliage samples of Spike hybrid poplar, hybrid willow, Norway spruce, and Streamco purpleosier willow were taken from the following replicate farms: two farms (Layer 1 and Layer 2), three farms (Broiler 1, Broiler 2, and Turkey), four farms (Broiler 1, Layer 1, Layer 2, and Turkey), and three farms (Broiler 1, Broiler 2, and Layer 2). Data are presented as individual and pooled of four plant species from five farms. a, b denote significant differences within plant species ($P \leq 0.05$); SEM for Spike hybrid poplar, hybrid willow, Norway spruce, Streamco purpleosier willow, and pooled foliar N are 0.19, 0.13, 0.09, 0.19, and 0.14, respectively.

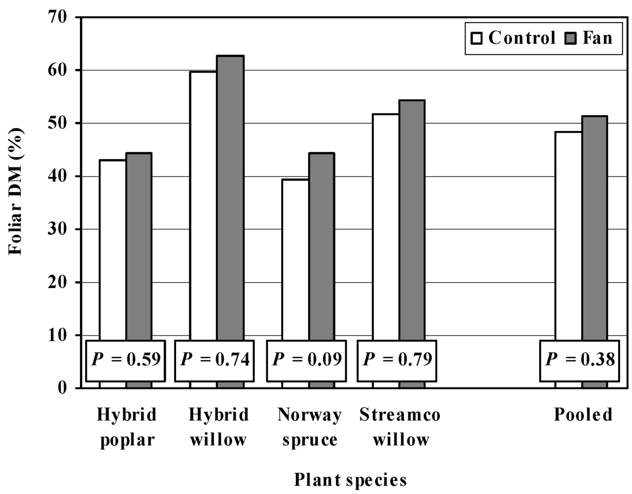


Fig. 4. Foliar dry matter (DM, %) of the plants sampled downwind of the fans in comparison with those sampled at a distance far away from the fans (control). Foliage samples of Spike hybrid poplar, hybrid willow, Norway spruce, and Streamco purpleosier willow were taken from the following replicate farms: two farms (Layer 1 and Layer 2), three farms (Broiler 1, Broiler 2, and Turkey), four farms (Broiler 1, Layer 1, Layer 2, and Turkey), and three farms (Broiler 1, Broiler 2, and Layer 2). Data are presented as individual and pooled (the four plant species from five farms); standard error of the means (SEM) for Spike hybrid poplar, hybrid willow, Norway spruce, Streamco purpleosier willow, and pooled foliar DM are 1.7, 6.2, 1.9, 6.2, and 4.5, respectively.

Table 2. Foliar dry matter (DM, %) and nitrogen (N, % DM basis) of Spike hybrid poplar (*Populus deltoides* × *Populus nigra*) and Norway spruce (*Picea abies*) sampled at two locations (control vs. downwind of the exhaust fans) on two commercial poultry (layer) farms

Factors	*DM*	*N*
	(%)	(%, DM basis)
Location:		
Control	38.2^b	2.15^b
Fan	45.4^a	2.95^a
Plant species:		
Spike hybrid poplar	43.7^a	3.22^a
Norway spruce	39.9^b	1.88^b
Location × Species:		
Control × Spike hybrid poplar	43.0^a	2.56^b
Control × Norway spruce	33.3^b	1.74^c
Fan × Spike hybrid poplar	44.3^a	3.87^a
Fan × Norway spruce	46.4^a	2.03^{bc}
SEM[1]	1.3	0.17
Sources of variances:	Probabilities (*P*)	
Location	0.0001	0.0001
Plant species	0.0087	0.0001
Location × Plant species	0.0002	0.0072

[a−−c]Means in a column with no common superscripts differ significantly ($P \leq 0.05$).
[1]Standard error of the means, mean of two farms with three foliage samples each.

farms. On layer farms 1 and 2, both poplar and Norway spruce were available to evaluate location, species, and their interaction (Table 2). Both foliar DM and N were significantly greater among plants near the fans ($P \leq 0.0001$), and species differences showed much greater N (1.7-fold) and DM (1.1-fold) holding capacity for Spike hybrid poplar compared to Norway spruce. The interactions were also highly significant, showing the importance of both plant location and species. When plant location and species (hybrid willow and Streamco purpleosier willow) were compared on broiler farms 1 and 2, no significant differences were detected for foliar DM and N (%) (Table 3). Neither were there any significant interactions, although similar trends to those noted previously were associated with plant location.

Plant location had no significant effect on PM fractions (Table 4). However, there was a significant species influence on the capacity of the plant to trap particulates, with Norway spruce holding 5–fold more PM_{10} and 3–fold greater total PM than hybrid willow, and more than 6–fold greater than Spike hybrid poplar or Streamco purpleosier willow. Also, the interaction between location and plant species indicates ($P \leq 0.10$) that for Norway spruce, plants

Table 3. Foliar dry matter (DM, %) and nitrogen (N, % DM basis) of hybrid willow (*Salix matsudana* × *Salix alba*) and Streamco purpleosier willow (*Salix purpurea*) sampled at two locations (control vs. downwind of the exhaust fans) on two commercial poultry (broiler) farms

Factors	*DM (%)*	*N (%, DM basis)*
Location:		
Control	52.3	3.13
Fan	61.0	3.36
Plant species:		
Hybrid willow	51.4	3.24
Streamco purpleosier willow	61.9	3.25
Location × Species:		
Control × Hybrid willow	48.6	3.11
Control × Streamco purpleosier willow	56.0	3.16
Fan × Hybrid willow	54.2	3.38
Fan × Streamco purpleosier willow	67.9	3.34
SEM[1]	7.0	0.18
Sources of variances:	Probabilities (*P*)	
Location	0.2269	0.2018
Plant species	0.1494	0.9008
Location × Plant species	0.6599	0.8122

[1]Standard error of the means, mean of two farms with three foliage samples each.

near the fans can hold almost 7–fold greater total PM than control plants.

Discussion

Reduced aerial NH_3 downwind of poultry exhaust fans with greater distance observed in the present study corroborates the previous findings of this group and others.[14,18,19,23,24] Ammonia reduction was likely influenced by the presence of vegetation[23] as well as sorption by soil[25,26] and the fluctuation of the climate[26] around the farm. Ammonia concentration was reduced approximately 78% between 0 and 11.4 m downwind of the fans in the present study. Although labeled NH_3–N was not used in this work, greater foliar N concentration near the fans suggests entrapment and incorporation of airborne NH_3 by the plants.

Plants located 11.4 to 17.7 m downwind of the fans absorbed more NH_3–N than those planted 40 m away from the fans. Although the NH_3 concentration downwind of the fans at 11.4 to 30 m was not significantly different (ranging from 2.59 to 0.31 ppm h^{-1}), the lower foliar N at 40 m compared to the first row (11.4 to 17.7 m) coincides with the 78% drop in airborne NH_3. The present study further revealed a higher capacity for deciduous trees (Spike hybrid poplar and the two willow species) over evergreens (Norway spruce) to incorporate NH_3–N into their tissue. This species–dependent capacity of plants to utilize airborne NH_3 confirms our previous studies where poplar vs. Norway spruce showed a greater foliar N and DM in the face of hen–house exhausts.[20] This pattern was also shown by Streamco purpleosier willow or lilac in comparison with juniper or canaan fir.[18,19] The location by species effect on foliar N and DM with poplar and Norway spruce may be explained by the rates of tissue metabolism unique to each plant (evergreen vs. deciduous tree). Greater foliar N status of *Pinus sylvestris* near a hen house was observed by Kaupenjohann et al. [27] among healthy and damaged trees implying that NH_3 exposure is not always an advantage to the plants. The fact that no noticeable injuries were observed among all the plants in the present study at 11.4 to 17.7 m distances suggests not only their capacity to buffer fan emissions but also their ability to apparently benefit from the nutrients therein.

A plant's capacity to hold dust or PM is also different from one species to another. Interestingly the Norway spruce held more PM mass as PM_{10} and total PM than the other deciduous trees combined, particularly Spike hybrid poplar and Streamco purpleosier willow. However, hybrid willow (deciduous) had statistically comparable performance with Norway spruce at holding $PM_{2.5}$ and total PM. Perhaps needle arrangement or the waxy cuticle of the spruce influenced differences between it and the Spike hybrid poplar and Streamco purpleosier willow. Lin et al.[28] indicated that for odor dispersion, trees with a lower optical porosity, such as conifers, would be more effective than deciduous species. Additionally, plants with greater foliar surface roughness have a higher capacity to hold dust particulates.[13] Leaf surface area between deciduous and evergreens (broad-leaf vs. needle leaf) has been reported to be a factor in the greater capacity of the deciduous trees to absorb NH_3–N than the conifers.[19] Hybrid willow in the present study emulated the Norway spruce with its capacity to capture PM. The rapid growth of hybrid willow results in a larger silhouette than is typical of Streamco purpleosier willow, and dense leaves and lower porosity relative to Spike hybrid poplar probably enhance its capacity as an effective dust trap.

Conclusions

The capacity of various plant species to trap and benefit from ambient NH_3 around poultry farms has been demonstrated in this study. These findings confirm previous chamber and pot–in–pot field studies with controlled ambient NH_3. Plant foliage was also found to trap poultry house particulate matter. These findings suggest that planting multiple rows of trees downwind of exhaust fans may help reduce and/or disperse farm emissions, particularly NH_3 and dust. Deciduous trees (Spike hybrid poplar, hybrid willow, and Streamco purpleosier willow) were more effective

Table 4. Particulate matter weight ($PM_{2.5}$, PM_{10}, $PM_{>10}$, and total PM [mg cm^{-2}]) of plant foliage sampled at two locations (control vs. downwind of the exhaust fans) on five commercial poultry farms

Factors	$PM_{2.5}$	PM_{10}	$PM_{>10}$	*Total PM*[1]
		(mg cm^{-2})		
Location:				
Control	0.0032	0.0079	0.0005	0.0103
Fan	0.0031	0.0100	0.0017	0.0145
Plant species:				
Hybrid willow	0.0054^{a}	0.0047^{b}	0.0003	0.0102^{ab}
Spike hybrid poplar	0.0005^{b}	0.0033^{b}	0.0001	0.0038^{b}
Norway spruce	0.0054^{a}	0.0248^{a}	0.0033	0.0309^{a}
Streamco willow	0.0016^{ab}	0.0028^{b}	0.0005	0.0046^{b}
Location × Plant species				
Control × Hybrid willow	0.0060	0.0050	0.0004	0.0110
Control × Spike hybrid poplar	0.0005	0.0054	0.0001	0.0057
Control × Norway spruce	0.0042	0.0179	0.0007	0.0181
Control × Streamco willow	0.0025	0.0033	0.0007	0.0063
Fan × Hybrid willow	0.0047	0.0045	0.0003	0.0094
Fan × Spike hybrid poplar	0.0005	0.0012	0.0001	0.0018
Fan × Norway spruce	0.0065	0.0317	0.0059	0.0437
Fan × Streamco willow	0.0007	0.0024	0.0004	0.0094
SEM[2]	0.0022	0.0052	0.0014	0.0078
Sources of variances:		Probabilities (*P*)		
Location	0.9082	0.5833	0.2529	0.4569
Plant species	0.0432	0.0001	0.0519	0.0005
Location × Plant species	0.7206	0.2082	0.0899	0.0958

$^{a\text{–}b}$Means in a column with no common superscripts differ significantly ($P \leq 0.05$).
[1]The values may be slightly different from the sum of $PM_{2.5}$, PM_{10}, and $PM_{>10}$ in each row due to the round of each value to the closest decimal.
[2]Standard error of the means, mean of five farms with two ammonia tubes each.

in absorbing airborne NH_3–N, whereas Norway spruce and hybrid willow were more effective dust traps.

References

[1] Jones, W.; Morring, K.; Olenchock, S.A.; Williams, T.; Hickey, J. Environmental study of poultry confinement building. Am. Ind. Hyg. Assoc. J. **1984**, *45*, 760–766.

[2] Fangmeier, A.; Hadwiger-Fangmeier, A.; Van der Eerden, L.; Jäger, H.-J. Effects of atmospheric ammonia on vegetation — a review. Environ. Pollut. **1994**, *86* (1), 43–82.

[3] Singh, S.P.; Satsangi, G.S.; Khare, P.; Lakhani, A.; Kumari, K.M.; Srivastava, S.S. Chemosp. Global Change Sci. **2001**, *2*, 107–116.

[4] Donham, K.J.; Cumro, D.; Reynolds, S. Synergistic effects of dust and ammonia on the occupational health effects of poultry production workers. J. Agromed. **2002**, *2*, 57–76.

[5] Heber, A.J.; Bogan, B.W. The study and regulation of agricultural air quality in the U.S. In *Proc. Workshop on Agric. Air Qual.: State of the Science*, Potomac, MD, June 5–8, 2006; Aneja, V.P., Schlesinger, W.H., Knighton, R., Jennings, G., Niyogi, D., Gilliam, W., Duke, C.S., Eds.; Department of Communication Services, North Carolina State Univ.: Raleigh, NC, **2006**, 32–35.

[6] Krupa, S.V. Effects of atmospheric ammonia (NH_3) on terrestrial vegetation: a review. Environ. Pollut. **2003**, *124*, 179–221.

[7] The United States Environmental Protection Agency (US-EPA). In 2005-*April Revised EPA Report*: *National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data, 1970-2002*, Triangle Park, NC, USA. http://www.epa.gov/ttn/chief/trends/index.html (accessed December 2005).

[8] Borrelli, J.; Gregory, J.; Abtew, W. Wind barriers: a reevaluation of height, spacing, and porosity. Trans. ASAE **1989**, *32*, 2023–2027.

[9] Raupach, M.R.; Woods, N.; Dorr, G.; Leys, J.F.; Cleugh, H.A. The entrapment of particles by windbreaks. Atmosp. Environ. **2001**, *35*, 3373–3383.

[10] Patterson, P.H.; Adrizal. Management strategies to reduce air emissions: emphasis-dust and ammonia. J. Appl. Poult. Res. **2005**, *14*, 638–650.

[11] Tyndall, J.; Colletti, J. Mitigating swine odor with strategically designed shelterbelt systems: a review. Agroforestry Syst. **2007**, *69*, 45–65.

[12] Malone, B. Using trees to reduce dust and odor emissions from poultry farms. In *Proc. Poult. Information Exchange*, Sufers Paradise, Queensland, Australia, April 19, 2004; Poultry Information Exchange: Queensland, Australia, **2004**, 33–38.

[13] Leuty, T. Using shelterbelts to reduce odors associated with livestock production barns. Ministry of Agriculture, Food, and Rural Affairs: Ontario, CA. 2004. http://www.omafra.gov.on.ca/english/crops/facts/info_odours.htm (accessed October 2006).

[14] Pitcairn, C.E.R.; Leith, I.D.; Sheppard, L.J.; Sutton, M.A.; Fowler, D.; Munro, R.C.; Tang, S.; Wilson, D. The relationship between nitrogen deposition, species composition, and foliar nitrogen concentrations in woodland flora in the vicinity of livestock farms. Environ. Pollut. **1998**, *102* (S1), 41–48.

[15] Yin, Z.-H.; Kaiser, W.; Heber, U.; Raven, J.A. Effects of gaseous ammonia on intracellular pH values in leaves of C_3- and C_4-plants. Atmosp. Environ. **1998**, *32*, 539–544.
[16] National Research Council. Air Emissions. *Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs*; The National Academies Press: Washington, DC, USA, 2003; 1–13.
[17] Adrizal, A.; Patterson, P.H.; Hulet, R.M.; Bates, R.M. Growth and foliar nitrogen status of four plant species exposed to atmospheric ammonia. J. Environ. Sci. Health-B, **2006**, *41*, 1001–1018.
[18] Patterson, P.H.; Adrizal, A.; Hulet, R.M.; Bates, R.M.; Despot, D.A.; Wheeler, E.F.; Topper, P.A. The potential for plants to trap emissions from farms with laying hens: 1. Ammonia. J. Appl. Poult. Res. **2007**, Accepted.
[19] Patterson, P.H.; Adrizal, A.; Hulet, R.M.; Bates, R.M.; Despot, D.A.; Wheeler, E.F.; Topper, P.A.; Thompson, J. The potential for plants to trap emissions from farms with laying hens: 2. Dust and ammonia. Unpublished research.
[20] Patterson, P.H.; Adrizal, A.; Hulet, R.M.; Bates, R.M.; Myers, C.; Martin, G.; Shockey, R.; van der Grinten, M. Vegetative buffers for fan emissions from poultry farms: 1. Temperature and foliar nitrogen. J. Environ. Sci. Health-B, **2007**, *42*, 5: in press.
[21] Ewing, R.; Kaspar, T. Accruate perimeter and length measurement using an edge chord algorithm. J. Computer-Assisted Microscopy **1995**, *7*, 91–100.
[22] SAS Institute. *SAS User's Guide: Statistics*, Version 8 edition; SAS Institute, Inc.: Cary, NC, 1999.
[23] Franzaring, J.; Frangmeier, A. Plant ecological approaches to monitor the effects of N-deposition in the field. In *Expert Workshop on Empirical Critical Loads for Nitrogen*, Berne, November 11–13, 2002. Swiss Agency for the Environment, Forest, and Landscape, Berne, Switzerland, **2003**, 297–302.
[24] Pitcairn, C.E.R.; Skiba, U.M.; Sutton, M.A.; Fowler, D.; Munro, R.; Kennedy, V. Defining the special impacts of poultry farm ammonia emissions on species composition of adjacent woodland groundflora using Ellenberg Nitrogen Index, nitrous oxide, and nitric oxide emissions and foliar nitrogen as marker variable. Environ. Pollut. **2002**, *119*, 9–21.
[25] McGinn, S.M.; Janzen, H.H.; Coates, T. Atmospheric pollutants and trace gases. J. Environ. Qual. **2003**, *32*, 1173–1182.
[26] Hao, X.; Chang, C.; Janzen, H.H.; Clayton, G.; Hill, B.R. Sorption of atmospheric ammonia by soil and perennial grass downwind from two large cattle feedlots. J. Environ. Qual. **2006**, *35*, 1960–1965.
[27] Kaupenjohann, M.; Döhler, H.; Bauer, M. Effects of N-immissions on nutrient status and vitality of *Pinus sylvestris*. Plant and Soil, **1989**, *113*, 279–282.
[28] Lin, X.J.; Barrington, S.; Nicell, J.; Choinière, D.; Vézina, A. Influence of windbreaks on livestock odor dispersion plume in the field. Agric. Ecosyst. Environ. **2006**, *116*, 263–272.