



## Foliar Nitrogen Status and Growth of Plants Exposed to Atmospheric Ammonia (NH<sub>3</sub>)

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### Abstract

Two experiments were conducted to evaluate the potential of plant species to trap NH<sub>3</sub> discharged from poultry houses. The four plant species (cedar, locust, poplar, and grass) used in experiment (Exp) 1 and four species (spruce, arborvitae, poplar, and willow) used in Exp 2 were transplanted into 4- to 8-L pots and grown in four environmentally controlled chambers. Two of the four chambers received continuous anhydrous NH<sub>3</sub> at 4 to 5 ppm (Exp 1) or 6 to 8 ppm (Exp 2) while the other two chambers in each experiment received no NH<sub>3</sub>. The results of Exp 1 showed that locust was the fastest growing species, supported by its total biomass, root, and root DM weights. There was a trend for all the plants exposed to NH<sub>3</sub> to have greater leaf DM than their non-exposed counterparts at 6 (43.0 vs. 30.8%;  $P=0.09$ ) and 12 wk (47.9 vs. 36.6%;  $P=0.07$ ), and significantly greater ( $P\leq 0.05$ ) leaf N at 6 (6.44 vs. 3.67%) and 12 wk (7.05 vs. 3.51%) when exposed to NH<sub>3</sub>. An increase in leaf N due to NH<sub>3</sub> exposure was also noted in Exp 2 (4.99 vs. 2.83%;  $P\leq 0.05$ ), but with no indication with species interaction. Numerically greater leaf DM due to NH<sub>3</sub> exposure was consistently measured in poplar tissues at both sampling periods in Exp 1. In Exp 1, poplar, as well as locust and grass, deposited 1.5 to 2 fold greater N in their leaves than cedar tissues as a result of NH<sub>3</sub> exposure compared to non-exposed plants. Similar numerical trends in foliar N were also observed in poplar, willow and arbovitae in Exp 2 ( $P > 0.05$ ). Locust (Exp 1) likely benefited from ambient NH<sub>3</sub> while poplar and willow (Exp 1 and 2) were negatively affected by atmospheric NH<sub>3</sub>.

### Introduction

Ammonia (NH<sub>3</sub>) is the foremost gas of concern in poultry houses. Feed can be a major contributor of this gas since NH<sub>3</sub>-N losses as a percentage of dietary feed-N range from 18 to 40% depending on type of bird (broiler, turkey, pullet, or laying hen) (Patterson and Lorenz, 1996, 1997, Patterson et al., 1998; Patterson et al., 1999), age, and management style. Both dietary and in-house management strategies are utilized to reduce the generation and emission of NH<sub>3</sub> inside the house, but offer no benefit once it is discharged via the exhaust fans. Field observations since 2003 on Pennsylvania poultry farms indicate that neighbors are concerned about emissions around many poultry production sites (unpublished data). However, concentrations of the airborne NH<sub>3</sub> once it is discharged by the exhaust fans is not well documented, and is dependent on the fan performance, outside wind speed, distance of measurement from the exhaust fan, and the presence of vegetation (Seedorf and Hartung, 2000; Pitcairn et al., 1998).

Yin et al. (1998) reported it is possible for atmospheric NH<sub>3</sub> to enter plants through foliar stomata and assimilate into plant cells through the glutamine synthetase and glutamate synthase pathways at up to 5.51 ppm NH<sub>3</sub> for short periods of time without disturbing photosynthesis or transpiration. Hence, at favorable concentrations, NH<sub>y</sub> (NH<sub>3</sub> + NH<sub>4</sub><sup>+</sup>) will induce plant growth while at a critical threshold NH<sub>3</sub> will cause necrosis, growth reduction, and increased frost sensitivity (Van deer Eerden et al., 1998). The objective of this study was to evaluate the tolerance of some plant species to NH<sub>3</sub> exposure released at a concentration range commonly detected near commercial poultry farms.

## Materials and Methods

Four plant species were grown in environmentally controlled chambers up to 12 wk in Experiment (Exp) 1 or 6 wk in Exp 2. The plants comprised of 53 four-yr-old red cedar (*Juniperus virginiana*), 40 one-yr-old thornless honey locust (*Gleditsia triacanthos* var. *inermis*), 57 one-yr-old hybrid poplar (*Populus sp.*), and 58 uniform clumps of reed canary-grass (*Phalaris arundinacea*) in Exp 1. In Exp 2 45 3-yr-old white spruce (*Picea glauca*), 45 3-yr-old arbovitae (*Thuja spp.*), 46 two-yr-old poplar, and 32 two-year-old streamco willow (*Salix purpurea*) were utilized. All the plants were transplanted into 4- and 8-L pots containing NX-6 pine bark media and placed onto two tables in each chamber. Two of the four chambers were treated with (+) NH<sub>3</sub> exposure at 4 to 5 ppm (Exp 1) or 5 to 7 (Exp 2) and the other two in each experiment received no (-) NH<sub>3</sub>. Each plant species in each chamber of Exp 1 was divided into two groups with no fertilizer (-) or NPK fertilizer at 100 ppm (+) once a week. All plants in Exp 2 received the fertilizer.

The anhydrous NH<sub>3</sub> was released from a 150-L NH<sub>3</sub> tank via a flow meter, monitored by a photoacoustic NH<sub>3</sub> detector (Model 1412, Innova, DK-2750 Ballerup, Denmark) weekly and backed-up with passive dosi-tube readings (3D, Gastec Corp., 6431 Fukaya, Japan). The lighting program was set for 16 h light and 8 h dark (16L:8D) every day for all chambers and light intensity was maintained at minimum (Exp 1) or medium requirements (Exp 2). Chamber temperature (T) and relative humidity (RH) were programmed to meet the required level for plant growth. Two fertilized plants per species per chamber were sampled on wk 0, 6, (Exp 1 and 2), and 12 (Exp 1) for fresh plant biomass wt, root wt, root DM, foliar DM and N analyses. Plant height and stem diameter were recorded on all plants only in Exp 1.

Data were subjected to a split plot design analysis of Proc Mixed of SAS (SAS Institute, 1999). Model 1 was used to analyze foliar DM and N data of Exp 1 and 2, while Model 2 was used to analyze plant height and plant diameter data obtained from Exp 1. The two models are as described below:

$$X_{ijk} = \mu + A_i + C(A_i)_j + S_k + AS_{ik} + \varepsilon_{(ijk)} \dots\dots\dots \text{(Model 1)}$$

$$X_{ijkl} = \mu + A_i + C(A_i)_j + S_k + F_l + AS_{ik} + AF_{il} + SF_{kl} + ASF_{ikl} + \varepsilon_{(ijkl)} \dots\dots \text{(Model 2)}$$

where  $X_{ijk}$  or  $X_{ijkl}$  is the value observed,  $\mu$  is the overall mean, A is the effect of NH<sub>3</sub> (main plot factor), C(A) is the error for A (where C = chamber, which is nested in A), S and F are the effects of species and fertilizer (sub plot factors), respectively, AS is the interaction effect of NH<sub>3</sub> by species, AF is the interaction effect of NH<sub>3</sub> by fertilizer, SF is the interaction effect of species by fertilizer, ASF is the interaction effect of NH<sub>3</sub> by species by fertilizer, and  $\varepsilon$  is the residual error. Tukey's test (SAS Institute, 1999) was employed to the data showing significance ( $P \leq 0.05$ ).

## Results

The average daily T and RH ranged from 24 to 24.7 °C and 44.3 to 44.7%, in the (-) and (+) NH<sub>3</sub> chambers, respectively in Exp 1, while in Exp 2 they were 24.2 to 24.7 °C and 44.8 to 45%, respectively. Light intensity averaged 1522 lux in Exp 1 and 3049 lux in Exp 2. The concentrations of NH<sub>3</sub> ranged from 0.08 to 0.20 ppm in the (-) NH<sub>3</sub> chambers (Exp 1 and 2) and 4 to 5 ppm (Exp 1) and 6 to 8 ppm (Exp 2) in the (+) NH<sub>3</sub> chambers.

### Experiment 1

Species had a significant effect ( $P \leq 0.05$ ) on plant height and stem diameter in Exp 1 (Table 1). Although the significant effect of species by fertilizer at 6 wk existed ( $P \leq 0.05$ ) it did not indicate a trend of plant height with fertilizer. Species was the only factor to influence total fresh biomass wt and fresh root wt (Figure 1) at all weeks in Exp 1 ( $P \leq 0.05$ ). A significant effect of species was also observed on plant root DM. An increased root DM due to the interaction of NH<sub>3</sub> by species was only numerical particularly in locust (46.7 to 56.1%) at 12 wk (data are not shown).

There was a repeatable trend of the NH<sub>3</sub> treatment to increase leaf DM at 6 ( $P=0.09$ ) and 12 wk ( $P=0.07$ ) and a highly significant NH<sub>3</sub> effect on N deposition in plant foliage at both weeks (Table 2). Leaf DM content appeared to be positively impacted by the NH<sub>3</sub> treatment in the case of red cedar and hybrid poplar at week 6 ( $P=0.07$ ) and upon hybrid polar at 12 wk ( $P=0.06$ ) but not so for locust or reed canary grass. Moreover, the NH<sub>3</sub> by species interaction was highly discernable in leaf N levels with greater concentrations at 6 and 12 wk for locust, poplar, and grass as a result of NH<sub>3</sub> exposure. Total foliar N of the fresh leaf material at 6 and 12 wk was calculated by difference between control (-) and (+) NH<sub>3</sub> chambers to be 0.45 and 0.87 g 100 g<sup>-1</sup> of fresh foliage weight for grass, 1.25 and 1.34 g for locust, and 2.67 and 6.09 g for poplar based on the leaf DM and N concentrations reported in Figure 2.

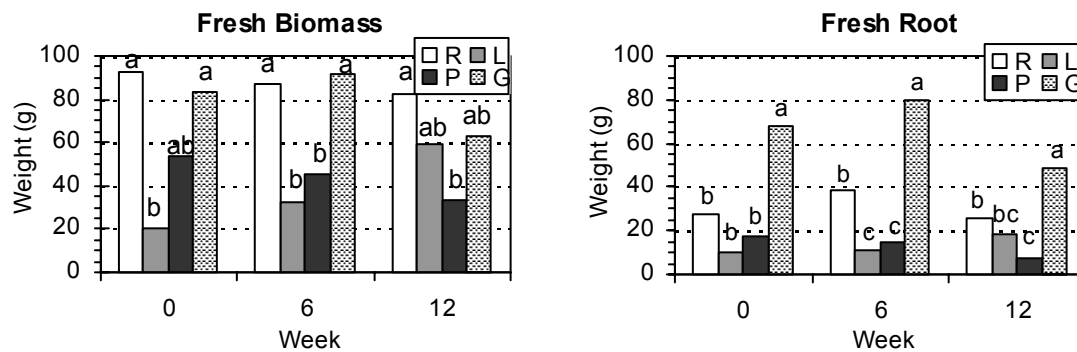
**Table 1. Plant heights and stem diameters of plants treated with (+) or without (-) atmospheric ammonia (NH<sub>3</sub>) for 12 wk, Exp 1.**

Treatment	Height (cm)			Stem Diameter <sup>2</sup> (cm)		
	Wk 0	Wk 6	Wk 12	Wk 0	Wk 6	Wk 12
NH <sub>3</sub> : (-)	53.8	66.0	68.5	0.72	0.70	0.70
(+)	53.4	65.1	65.4	0.74	0.70	0.71
Species (Spec):						
Red cedar (R)	48.2 <sup>b</sup>	46.3 <sup>c</sup>	46.9 <sup>c</sup>	0.87 <sup>a</sup>	0.77 <sup>a</sup>	0.78 <sup>a</sup>
Honey locust (L)	54.6 <sup>ab</sup>	83.1 <sup>a</sup>	88.0 <sup>a</sup>	0.60 <sup>b</sup>	0.62 <sup>b</sup>	0.64 <sup>b</sup>
Hybrid poplar (P)	57.8 <sup>a</sup>	69.0 <sup>b</sup>	68.7 <sup>b</sup>	0.71 <sup>b</sup>	0.71 <sup>b</sup>	0.69 <sup>b</sup>
Reed canary grass (G)	53.9 <sup>ab</sup>	63.8 <sup>b</sup>	64.2 <sup>b</sup>	-	-	-
Fertilizer (Fert): (+)	52.7	66.0	67.8	0.71	0.67	0.68
(-)	54.5	65.1	66.1	0.74	0.73	0.73
Spec x Fert:						
R x (+)	48.6	45.0 <sup>e</sup>	45.2	0.86	0.72	0.74
R x (-)	47.8	47.5 <sup>de</sup>	48.5	0.88	0.81	0.81
L x (+)	54.1	85.7 <sup>a</sup>	92.8	0.57	0.61	0.65
L x (-)	55.0	80.5 <sup>ab</sup>	83.3	0.63	0.62	0.64
P x (+)	54.1	64.8 <sup>bc</sup>	65.7	0.70	0.66	0.65
P x (-)	61.5	73.1 <sup>abc</sup>	71.7	0.72	0.77	0.73
G x (+)	54.1	68.3 <sup>bc</sup>	67.4	-	-	-
G x (-)	53.7	59.3 <sup>cd</sup>	61.0	-	-	-
NH <sub>3</sub> x Spec:	... <sup>1</sup>	...	...	...	...	...
NH <sub>3</sub> x Fert:	...	...	...	...	...	...
NH <sub>3</sub> x Spec x Fert	...	...	...	...	...	...
Sources of Variances:	----- Probabilities -----					
NH <sub>3</sub>	0.94	0.71	0.52	0.80	0.90	0.72
Spec	0.04	0.0001	0.0001	0.0002	0.03	0.04
Fert	0.45	0.71	0.57	0.51	0.14	0.27
Spec x Fert	0.53	0.05	0.19	0.94	0.65	0.62
NH <sub>3</sub> x Spec	0.83	0.95	0.21	0.91	0.42	0.71
NH <sub>3</sub> x Fert	0.64	0.11	0.07	0.74	0.91	0.45
NH <sub>3</sub> x Spec x Fert	0.52	0.83	0.82	0.93	0.98	0.82

<sup>a-e</sup>Means in a column with no common superscripts differ significantly ( $P \leq 0.05$ ).

<sup>1</sup>Mean values are not shown because they did not have significant probabilities ( $P \geq 0.05$ ).

<sup>2</sup>Measurements were taken only on red cedar, honey locust, and hybrid poplar.

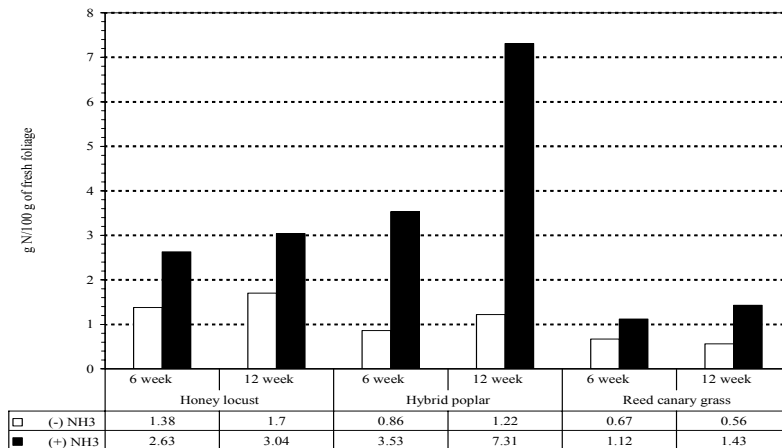


**Figure 1. Fresh biomass and root weight of the plants treated with (+) or without (-) NH<sub>3</sub> exposure, Exp 1.**

**Table 2. Leaf dry matter (DM) and nitrogen (N) concentration of plants treated with (+) or without (-) atmospheric ammonia (NH<sub>3</sub>) exposure for 12 wks Exp 1.**

Treatment	DM (%)			N (%)		
	Wk 0	Wk 6	Wk 12	Wk 0	Wk 6	Wk 12
NH <sub>3</sub> : (-)	27.1	30.8	36.6	3.84	3.67 <sup>b</sup>	3.51 <sup>b</sup>
(+)	26.9	43.0	47.9	3.82	6.44 <sup>a</sup>	7.05 <sup>a</sup>
Species:						
R	46.9 <sup>a</sup>	70.9 <sup>a</sup>	64.2 <sup>a</sup>	1.63 <sup>c</sup>	1.95 <sup>c</sup>	2.26 <sup>c</sup>
L	26.9 <sup>b</sup>	25.8 <sup>b</sup>	32.8 <sup>bc</sup>	4.92 <sup>a</sup>	7.46 <sup>a</sup>	7.15 <sup>a</sup>
P	19.1 <sup>c</sup>	28.9 <sup>b</sup>	51.0 <sup>ab</sup>	5.35 <sup>a</sup>	6.81 <sup>a</sup>	7.12 <sup>a</sup>
G	15.1 <sup>c</sup>	22.1 <sup>b</sup>	21.0 <sup>c</sup>	3.41 <sup>b</sup>	4.00 <sup>b</sup>	4.61 <sup>b</sup>
NH <sub>3</sub> x Species:						
(-) x R	47.5	57.6	64.8	1.53	1.57 <sup>d</sup>	1.84 <sup>e</sup>
(-) x L	26.8	25.1	31.9	4.88	5.49 <sup>b</sup>	5.32 <sup>bc</sup>
(-) x P	18.8	18.9	30.3	5.49	4.55 <sup>b</sup>	4.04 <sup>cd</sup>
(-) x G	15.2	21.7	19.5	3.45	3.08 <sup>c</sup>	2.86 <sup>de</sup>
(+) x R	46.2	84.1	63.5	1.74	2.34 <sup>cd</sup>	2.68 <sup>de</sup>
(+) x L	27.1	26.5	33.8	5.00	9.44 <sup>a</sup>	8.99 <sup>a</sup>
(+) x P	19.3	38.9	71.7	5.20	9.07 <sup>a</sup>	10.20 <sup>a</sup>
(+) x G	15.0	22.6	22.5	3.37	4.91 <sup>b</sup>	6.36 <sup>b</sup>
Sources of Variances:				Probabilities		
NH <sub>3</sub>	0.93	0.09	0.07	0.87	0.02	0.0001
Species	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001
NH <sub>3</sub> x Species	0.92	0.07	0.06	0.61	0.0001	0.0001

<sup>a-e</sup>Means in a column with no common superscripts differ significantly ( $P \leq 0.05$ ).



**Figure 2. Total foliage N of the plants at 6 and 12 wk treated with (+) or without (-) NH<sub>3</sub> exposure (fresh leaf wt before and after NH<sub>3</sub> exposure at 6 wk were 8.95 and 9.0 g for locust, 10.88 and 9.33 g for poplar, and 9.93 and 13.6 g for grass, respectively; while at 12 wk they were 14.85 and 24.68 g for locust, 4.68 and 3.85 g for poplar, and 14.07 and 13.8 g for grass, respectively), Exp 1.**

There was a numerical trend for NH<sub>3</sub> exposure to increase leaf color scores at week 6 ( $P=0.10$ ) and 12 ( $P=0.09$ ) and mean leaf damage scores at week 6 ( $P=0.06$ ) and 12 ( $P=0.09$ ) (Table 3). There were also highly species-dependent responses to NH<sub>3</sub> as shown by higher leaf color and damage scores. This indicated that some species were sensitive to NH<sub>3</sub>, e.g. cedar, poplar, and grass whereas the locust color was enhanced by NH<sub>3</sub> treatment and showed lower damage values than other species.

## Experiment 2

The greater plant foliar N resulting from NH<sub>3</sub> exposure was apparent at 6 wk compared with non-exposed plants (4.99 vs. 2.83%;  $P\leq 0.05$ ) (Table 4). A similar trend in foliar DM was also observed with NH<sub>3</sub> exposure (57.4 vs. 46.5%;  $P=0.16$ ). Poplar and willow deposited more N in their leaves than the other two species (arbovitae and spruce). Although the probability value did not indicate a significant NH<sub>3</sub> by species interaction on foliar N of the plants at 6 wk, the numerical trend toward greater foliar N in those exposed to NH<sub>3</sub> was discernable, particularly in arbovitae, poplar, and willow ( $P=0.13$ ). This was also supported by a numerical trend of foliar DM at the same period.

Higher average leaf color scores and leaf damage scores due to NH<sub>3</sub> exposure was also observed e.g. 3.48 vs. 3.08 ( $P=0.14$ ) and 4.51 vs. 4.40 ( $P=0.74$ ), respectively (Table 5). Different plant species showed different responses to NH<sub>3</sub> exposure with poplar and willow showing greater leaf color and damage scores than arbovitae and spruce. However, there were no NH<sub>3</sub> by species interactions observed for plant color and damage scores.

**Table 3. Leaf color and damage scores of plants treated with (+) or without (a) ammonia (NH<sub>3</sub>) exposure for 12 wk, Exp 1.**

Treatments	Color Score			Damage Score		
	Wk 0 <sup>1</sup>	Wk 6	Wk 12	Wk 0 <sup>1</sup>	Wk 6	Wk 12
NH <sub>3</sub> : (-)	2.21	2.12	2.86	1	2.60	4.42
(+)	2.21	2.50	3.22	1	4.05	5.40
Species (Spec):						
R	2.00	2.78 <sup>a</sup>	3.86 <sup>a</sup>	1	3.15 <sup>b</sup>	5.59 <sup>a</sup>
L	3.00	1.39 <sup>c</sup>	1.75 <sup>b</sup>	1	1.54 <sup>c</sup>	3.90 <sup>b</sup>
P	2.00	2.88 <sup>a</sup>	4.32 <sup>a</sup>	1	4.42 <sup>a</sup>	6.08 <sup>a</sup>
G	2.00	2.18 <sup>b</sup>	2.25 <sup>b</sup>	1	4.18 <sup>ab</sup>	4.07 <sup>b</sup>
Fertilizer (Fert):						
(+)	2.21	2.31	2.96	1	3.46	4.78
(-)	2.21	2.31	3.13	1	3.18	5.04
Spec x Fert:	... <sup>2</sup>	...	...	-	...	...
NH <sub>3</sub> x Spec:						
(-) x R	-	2.57 <sup>ab</sup>	3.90 <sup>ab</sup>	-	2.96 <sup>b</sup>	5.11 <sup>abc</sup>
(-) x L	-	1.62 <sup>bc</sup>	2.17 <sup>cd</sup>	-	1.20 <sup>c</sup>	4.54 <sup>bcd</sup>
(-) x P	-	2.44 <sup>ab</sup>	3.77 <sup>ab</sup>	-	2.55 <sup>b</sup>	5.17 <sup>abc</sup>
(-) x G	-	1.85 <sup>bc</sup>	1.62 <sup>cd</sup>	-	3.69 <sup>b</sup>	2.85 <sup>d</sup>
(+) x R	-	2.98 <sup>a</sup>	3.82 <sup>ab</sup>	-	3.35 <sup>b</sup>	6.06 <sup>ab</sup>
(+) x L	-	1.16 <sup>c</sup>	1.33 <sup>d</sup>	-	1.88 <sup>c</sup>	3.25 <sup>cd</sup>
(+) x P	-	3.31 <sup>a</sup>	4.87 <sup>a</sup>	-	6.28 <sup>a</sup>	6.99 <sup>a</sup>
(+) x G	-	2.51 <sup>ab</sup>	2.87 <sup>bc</sup>	-	4.68 <sup>ab</sup>	5.28 <sup>abc</sup>
NH <sub>3</sub> x Fert:	...	...	...	...	...	...
NH <sub>3</sub> x Spec x Fert	...	...	...	...	...	...
Sources of Variances:	----- Probabilities -----					
NH <sub>3</sub>	-	0.10	0.09	-	0.06	0.09
Spec	-	0.0001	0.0001	-	0.0001	0.0001
Fert	-	0.97	0.43	-	0.38	0.44
Spec x Fert	-	0.44	0.13	-	0.92	0.20
NH <sub>3</sub> x Spec	-	0.03	0.002	-	0.001	0.001
NH <sub>3</sub> x Fert	-	0.33	0.27	-	0.16	0.06
NH <sub>3</sub> x Spec x Fert	-	0.19	0.08	-	0.75	0.06

<sup>a-d</sup>Means in a column with no common superscripts differ significantly ( $P \leq 0.05$ ).

<sup>1</sup>Data at week 0 were not subjected to ANOVA because there were no differences within each species.

<sup>2</sup>Mean values are not shown because they did not have significant probabilities ( $P \geq 0.05$ ).

**Table 4. Leaf dry matter (DM) and nitrogen (N) concentration of plants treated with (+) or without (-) atmospheric ammonia (NH<sub>3</sub>) exposure for 6 wk, Exp 2.**

Treatment	DM (%)		N (%)	
	Wk 0	Wk 6	Wk 0	Wk 6
NH <sub>3</sub> : (-)	29.9	46.5	2.62	2.83 <sup>a</sup>
(+)	30.9	57.4	2.67	4.99 <sup>b</sup>
Species:				
Arbovitae (A)	41.2 <sup>a</sup>	37.9 <sup>b</sup>	1.75 <sup>c</sup>	3.12 <sup>b</sup>
Poplar (P)	22.8 <sup>c</sup>	77.1 <sup>a</sup>	3.35 <sup>b</sup>	4.86 <sup>a</sup>
Spruce (S)	33.5 <sup>b</sup>	39.5 <sup>b</sup>	1.45 <sup>c</sup>	2.10 <sup>b</sup>
Willow (W)	24.2 <sup>c</sup>	53.3 <sup>b</sup>	4.04 <sup>a</sup>	5.55 <sup>a</sup>
NH <sub>3</sub> × Species:				
(-) × A	39.7	34.5	1.67 <sup>c</sup>	2.24
(-) × P	22.9	79.3	3.54 <sup>ab</sup>	3.55
(-) × S	33.3	37.3	1.49 <sup>c</sup>	1.55
(-) × W	23.8	35.0	3.78 <sup>ab</sup>	3.96
(+) × A	42.7	41.3	1.83 <sup>c</sup>	4.00
(+) × P	22.7	75.0	3.15 <sup>b</sup>	6.17
(+) × S	33.7	41.8	1.41 <sup>c</sup>	2.65
(+) × W	24.6	71.5	4.29 <sup>a</sup>	7.14
Source of Variances:	----- Probabilities -----			
NH <sub>3</sub>	0.36	0.16	0.77	0.04
Species	0.0001	0.0001	0.0001	0.0001
NH <sub>3</sub> × Species	0.71	0.09	0.05	0.13

<sup>a-c</sup>Means in a column with no common superscripts differ significantly ( $P \leq 0.05$ ).

**Table 5. Leaf color and damage scores of plants treated with (+) or without (-) ammonia (NH<sub>3</sub>) exposure for 6 wk, Exp 2.**

Treatment	Color Score		Damage Score	
	Wk 0 <sup>1</sup>	Wk 6	Wk 0 <sup>1</sup>	Wk 6
NH <sub>3</sub> : (-)	2.02	3.08	1	4.40
(+)	2.00	3.48	1	4.51
Species:				
A	2.00	1.61 <sup>d</sup>	1	1.56 <sup>b</sup>
P	2.00	4.88 <sup>a</sup>	1	6.96 <sup>a</sup>
S	2.00	2.57 <sup>c</sup>	1	2.29 <sup>b</sup>
W	2.03	4.04 <sup>b</sup>	1	7.00 <sup>a</sup>
NH <sub>3</sub> x Species:				
(-) x A	2.00	1.50	1	1.40
(-) x P	2.00	4.92	1	6.92
(-) x S	2.00	2.54	1	2.27
(-) x W	2.00	3.33	1	7.00
(+) x A	2.00	1.73	1	1.73
(+) x P	2.00	4.85	1	7.00
(+) x S	2.00	2.60	1	2.30
(+) x W	2.00	4.75	1	7.00
Source of Variances:	----- Probabilities -----			
NH <sub>3</sub>	-	0.14	-	0.74
Species	-	0.0001	-	0.0001
NH <sub>3</sub> x Species	-	0.12	-	0.98

<sup>a-c</sup>Means in a column with no common superscripts differ significantly ( $P \leq 0.05$ ).

<sup>1</sup>Data at week 0 were not subjected to ANOVA because there were no differences within each species.

## Discussion

The superior growth of locust (Exp 1) compared with other species is likely due to the unique symbioses of its roots with bacteria in fixating air  $\text{NH}_3$  (Zahrán, 2001). Because the effect of fertilizer on plant heights at wk 6 did not show any impact within a species, this suggested that growth response of plants to fertilizer was unique to each species. Visual observation of red cedar in the (+)  $\text{NH}_3$  chambers in Exp 1 showed that new shoots became dry as they emerged indicating metabolic disturbance or necrosis, which was possibly due to  $\text{NH}_3$  exposure. The same symptoms occurred in Exp 2 with the spruce. Krupa (2003) reported that needle necrosis following needle drying was a common response of conifers to  $\text{NH}_3$  near livestock farms. These species will become very sensitive when they are exposed to  $\text{NH}_3$  for long periods of time (Van deer Eerden, 1982).

The greater leaf N of honey locust, hybrid poplar, and grass observed in Exp 1 and the numerical trend in Exp 2 indicated greater metabolism or detoxification of the absorbed  $\text{NH}_3$ -N (Fangmeier et al., 1994). However, greater N deposition in leaves does not necessarily mean that all the plants, especially hybrid poplar (Exp 1 and 2), grass (Exp 1), willow, and spruce (Exp 2) benefited from continuous atmospheric  $\text{NH}_3$  exposure in a closed chamber as shown by the poor leaf color quality and damaged leaves (Tables 3 and 5). Exposure to 4 to 5 ppm of  $\text{NH}_3$  under a 16L:8D photoperiod was seemingly sufficient to elicit the adverse effects of  $\text{NH}_3$  on these species. Black spots and necrosis indicated by leaf-tip drying were the two consistent symptoms of foliar tissues in the current experiments and consistent with the other findings as reviewed by Krupa (2003). Visual injury of the plant foliage is associated with  $\text{NH}_3$  exposure and increased arginine levels have been reported with yellowing of young needles in *Pinus sylvestris* (Roelofs, 1987a, 1987b). This type of injury was clearly seen among red cedar in Exp 1, spruce, and some arborvitae in Exp 2 in the (+)  $\text{NH}_3$  chambers. Visible injury in honey locust did not seem to be as great as in other species supporting the fact that this species might have benefited from  $\text{NH}_3$  exposure as also indicated by its superior growth.

It is important to note that Two-Spotted Spider Mites were in evidence among the locust, poplar, and cedar from week 6 on in the (+)  $\text{NH}_3$  chambers in Exp 1, although all the plants were sprayed with a miticide at the start of the experiment and again at 3 and 6 wk. The presence of these mites might have contributed to leaf color and damage scores of the plants since one of the contributing effects of elevated leaf N due to  $\text{NH}_3$  exposure is increased sensitivity to insect pest infestation (Krupa, 2003). Therefore, it was not surprisingly to find numerically greater damage scores of all plants in the (+)  $\text{NH}_3$  chamber compared to those in the (-)  $\text{NH}_3$  chambers at 6 and 12 wk in Exp 1 (Table 3).

Overall, this study demonstrated that plant foliage has the potential to absorb  $\text{NH}_3$ -N discharged from the exhaust fans of poultry and livestock barns. As an example, assume the average concentration of  $\text{NH}_3$  in a small hen house (4,000 birds) with four 61-cm exhaust fans is 30 ppm (Wathes et al., 2003; Miles et al., 2004) (equivalent to  $0.020833 \text{ g m}^{-3}$  [Krupa, 2003]), and each of the four 61-cm fans is discharging  $140,213 \text{ m}^3$  of air  $\text{d}^{-1}$ , and if approximately 30% of  $\text{NH}_3$ -N is trapped by the plant foliage; then the foliar biomass required to trap this amount of  $\text{NH}_3$ -N will be 47 to 108  $\text{kg d}^{-1}$  of poplar, 215 to 231  $\text{kg d}^{-1}$  of locust, or 331 to 665  $\text{kg d}^{-1}$  of grass based on the data herein. With this knowledge one can calculate the foliar biomass and number of trees or grasses to plant around a commercial poultry house to reduce ammonia emissions and environmental pollution.

## Conclusions

Foliar condition and nutrient concentration appeared to be the more sensitive plant indicators of continuous anhydrous  $\text{NH}_3$  exposure in environmentally controlled chambers. Although almost all the species deposited more N in their leaves due to  $\text{NH}_3$  exposure, only honey locust appeared to tolerate and might have benefited from the continuous 4 to 5 ppm  $\text{NH}_3$  exposure.

## Acknowledgements

The assistance of farm technicians, staff, and students from the Department of Poultry Science during data collection is appreciated. David Despot, a plant research technician from the Department of Horticulture contributed significantly to the project. We are also thankful to Patrick Topper and Dr. Eileen Wheeler from the Department of Agriculture and Bio Engineering, who helped us with their photoacoustic unit monitoring  $\text{NH}_3$  concentration.

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