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UPTAKE OF ATMOSPHERIC AMMONIA BY SELECTED PLANT SPECIES

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ROGERS H. H. and ANEJA V. P. *Uptake of atmospheric ammonia by selected plant species.* ENVIRONMENTAL AND EXPERIMENTAL BOTANY **20,** 251–257, 1980.—Rates of NH_3 uptake were measured for 10 crop species by direct kinetic techniques. A continuous stirred tank reactor (CSTR) system designed for plant gas exchange studies was used in the NH_3 exposures. Ammonia was monitored with an analyzer that permitted real time measurement of atmospheric NH_3 down to 5 ppb. This permitted measurement of dynamic sorption of NH_3 at concentrations much closer to ambient levels than previously reported. Uptake rates increased with increasing light, temperature, and NH_3 concentration. An inverse correlation was observed between total diffusion resistance of leaves and NH_3 sorption. Rates did not vary significantly with repeated exposure or with changes in growth media N.

INTRODUCTION

NITROGENOUS gases from natural and man-made sources are responsible for a significant amount of air pollution. Man-made sources account for about 5.7×10^7 tons annually, principally as NO, NO_2, and NH_3, while natural sources contribute about 6.4×10^9 tons, mainly as NH_3.[14] Atmospheric NH_3 is present in concentrations ranging from less than 5 to 75 ppb.[14]

The capacity of plants to remove various atmospheric contaminants and the need for research in this area has been discussed by several authors.[3, 6, 8, 13] Sinks for air pollutants are an important aspect in planning air pollution control strategies. Also of significance is a consideration of the role of these gas exchange phenomena in plant nutrition.

FALLER,[7] working with NH_3 in long duration gassing experiments of aerial portions of plants, demonstrated that NH_3 could serve as the only source of N without affecting normal growth or development. In these experiments, the lowest level of NH_3 used was 20 times that of the average ambient concentration; therefore, the extrapolation of these results to ambient conditions might be questioned. PORTER *et al.*[12] showed that leaves could absorb gaseous NH_3 by exposing them to concentrations of $^{15}NH_3$ greater than 1 ppm for a period of 24 hr. HUTCHINSON *et al.*[9] monitored the disappearance of NH_3 from an air stream flowing through a small chamber containing the aerial

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portion of a single plant and calculated the amount absorbed by the plant as the difference in the amount of NH_3 in the inflow and outflow. Their results indicated that plant leaves absorb significant quantities of NH_3 from the air and determined that the NH_3 uptake rate of soybean was 4.2 $\mu g/dm^2/hr$ and that of corn was 5.6 $\mu g/dm^2/hr$. However, they used a wet chemical technique (KCl trapping with HCl titration) which is less accurate than the technique used in this investigation for NH_3 measurement. MEYER[11] measured plant absorption of $^{15}NH_3$ and established that plants are atmospheric sinks for NH_3 in air. He was unable to account for 60% of the NH_3 placed in the test atmosphere, but he also used a wet chemical method to measure NH_3 concentration.

Fescue growing downwind of animal feedlots is reported to show increased vigor, presumably due to NH_3 emanating from such operations.[4] Certain attempts to balance N budgets in minimum tillage cropping systems involving fescue have shown that N was entering from an unknown source; it has been suggested that this source could be fixed N from the atmosphere.[4]

In order to understand further the sorption rate of atmospheric NH_3, it seemed necessary to improve the methods of dispensing and monitoring lower concentrations of gaseous NH_3 and to evaluate further the factors influencing the rate of NH_3 uptake in various plants. The following study was therefore designed to address three objectives: (I) Assess the performance of a continuous stirred tank reactor (CSTR) system and an ambient NH_3 monitoring method in assessing NH_3 sorption by plants. (II) Determine the rate of NH_3 uptake in 10 major agricultural crop species. (III) Determine the effect of NH_3 concentration, tissue nitrogen content, light intensity, repeated exposure to NH_3, and exposure temperature on the rate of NH_3 absorption by snap bean.

MATERIALS AND METHODS

Measurement of uptake

The exposure system, which was housed in a controlled environment room of the North Carolina State University Phytotron,[5] consisted of two CSTRs designed for gas exchange studies.[17] Each 200-l. exposure reactor was cylindrical and consisted of a Teflon coated steel frame covered by 5 mil Teflon (FEP) film (Fig. 1). The configuration of each exposure unit along with an impeller (120 RPM) produced uniform mixing.[1] All internal surfaces were made of Teflon or glass to minimize wall losses.

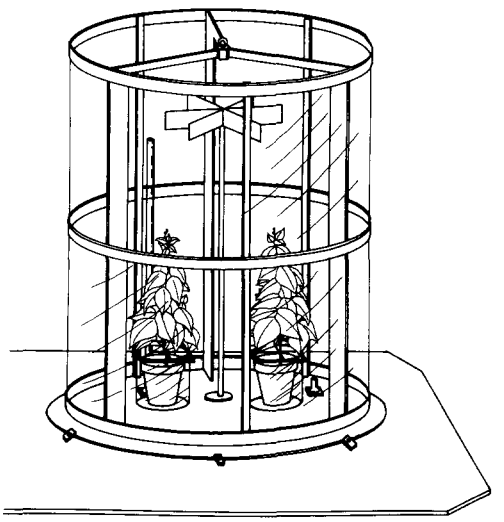

FIG. 1. A single unit of the dual CSTR system during exposure of two snap bean plants. The glass inlet near the impeller, the outlet near the bottom of the right plant, and the glass enclosures around the pots are shown.

Plant pots were inserted into glass containers with split plate glass lids, the interfaces of which were sealed with a fluorocarbon grease. Plants were then placed inside the exposure system by lifting the units from gasketed bases. These containers permitted uptake of NH_3 and loss of water vapor by plant tops only, thus allowing calculation of NH_3 sorption rates by leaves and total diffusion resistance (stomatal plus aerodynamic).[15] Experimental runs without plants provided correction factors for wall effects.

Ammonia was supplied to the system from a permeation tube using N_2 as a carrier. The flow rate into each exposure unit was 10 l/min. The level of NH_3 was controlled by using different

sizes and numbers of permeation tubes. The common inlet to both chambers and separate outlets were sampled in sequence for 5 min each. A timer, which actuated Teflon solenoids, controlled sampling through 0.635 cm Teflon (FEP) tubing. The tubing fed into a heated glass manifold that supplied the analyzers. The NH_3 was continually monitored with a Monitor Labs Model 8440 Oxides of Nitrogen Analyser equipped with a catalytic converter that was maintained at 800°C to oxidize NH_3 to NO.[2]

Injection of NH_3 began as soon as plants were placed in the exposure unit. Sorption rate was computed by the difference between inlet and outlet concentration, once steady state was reached. However, rate may also be determined during dynamic phases, permitting rate calculations for the entire exposure concentration range. The following mass balance equation[10] for a CSTR was used as a starting point to compute the NH_3 sorption rate:

$$r = (f/V)(C_{out} - C_{in}) + \frac{dC_{out}}{dt}$$

where r = rate of reaction, mass/vol/time
f = flow rate into and out of volume V
C = concentration, mass per unit volume

This equation yields rate as pphm/min, which is then corrected for wall effects and converted to the units herein reported ($\mu g/dm^2/min/pphm$) by substitution of units and then dividing by C_{out} (which is the exposure concentration) and leaf area.

Total diffusion resistance was computed from measures of transpiration, leaf area (i.e., outline area of leaf profile), and temperatures and water vapor concentrations of leaves and air. The following instruments were used: EG & G Model 880 Dew Point Hygrometer for dew point temperature, 44203 Yellow Springs Thermistors for air temperature, no. 36-gauge Type T thermocouples for leaf temperature, and a Lambda 3100 Area Meter for leaf area.

Plants and growth conditions

The following species were chosen for the survey portion of this experiment because they represent 10 economically important and widely distributed agricultural crops: corn (*Zea mays* L. "Pioneer Brand 3369A"), cotton (*Gossypium hirsutum* L. "Stoneville 213"), fescue (*Festuca arundinacea* Schreb. "Kentucky 31 Tall Fescue"), oat (Avena sativa L. "Carolee"), orchard grass (*Dactylis glomerata* L. "Potomac"), snap bean (*Phaseolus vulgaris* L. "*Bush Blue Lake* 274" and "Bush Blue Lake 290"), soybean (*Glycine max* (L.) Merr. "Davis"), tobacco (*Nicotiana tabacum* L. "NC 2326"), tomato (*Lycopersicon esculentum* Mill. "Walter"), and wheat (*Triticum aestivum* L. "Butte").

Plants were grown in a controlled environment room under 9–hr light periods at 40.5 klx (600 μEinsteins/m^2/s between 400 and 700 nm) with temperatures of 26°C (day) and 22°C (night), relative humidities of 55–70% (day) and 70–80% (night), and at carbon dioxide levels of 350 to 400 ppm. Each plant was grown in a 177 ml Styrofoam cup containing a 1:2 mixture of peat-lite and gravel and watered in the morning with deionized water and in the afternoon with nutrient solution.[5] Plant age at time of exposure ranged from 2 to 6 weeks from seed, depending upon germination and development rate.

Factors influencing uptake

Bush Blue Lake 290 (BBL-290) snap beans were chosen for the second series of experiments because this plant is being studied in-depth in our laboratory and because it represents an important member of a group of agricultural species. The plants were grown and exposed under conditions previously listed except for the changes required by the tests discussed in this section. To determine the relationship between rate and concentration, snap beans were exposed to three levels of NH_3, one hour for each level. To determine the effect of tissue nitrogen, plants were grown under nutrient regimes of varying N content. The Kjeldahl procedure was used to determine the N content of unexposed snap bean tops. Light was stepped through four levels (0, 73, 146, and 326 μEinsteins/m^2/sec) of 1 hr duration each in a single experimental run. In another test, duplicate sets of four BBL-290 plants were exposed to NH_3 for 3 hr in the middle of the day for 7 days. Two replicate

runs had exposure temperatures of 22, 26 and 30°C.

Light was measured with a Lambda Model LI-185 Quantum/Radiometer/Photometer as either illumination (lx) or as photosynthetically active radiation (PAR: μEinsteins/m^2/sec).

RESULTS AND DISCUSSION

Exposure system

The CSTR exposure system performed satisfactorily and permitted the assessment of a continuous rate of NH_3 sorption. The thermal catalytic converter along with the nitrogen oxides analyzer permitted the measurement of NH_3 to concentrations as low as 5 ppb with a response time of less than 2 min.

The first order rate constant for wall reaction averaged 0.014 min^{-1}. With an average residence time of 20 min and no plants in the system, if 100 pphm of NH_3 were fed in, 78 pphm would be flowing out once steady state was achieved. The wall reaction rate constant was found to be independent of NH_3 concentration and was subtracted from the overall rate constant (plants plus walls).

Figure 2 is a dynamic plot of the NH_3 concentration at the common inlet and the two chamber outlets during fescue exposures. The difference in steady state outlet concentrations was due to differences in leaf area of the fescue in the two chambers. The consistent rate of sorption suggested that the NH_3 was being metabolized as was shown by PORTER *et al.*[12] rather than accumulating in the leaf tissue. The rate would probably be reduced significantly if there were buildup of NH_3 in the tissue.

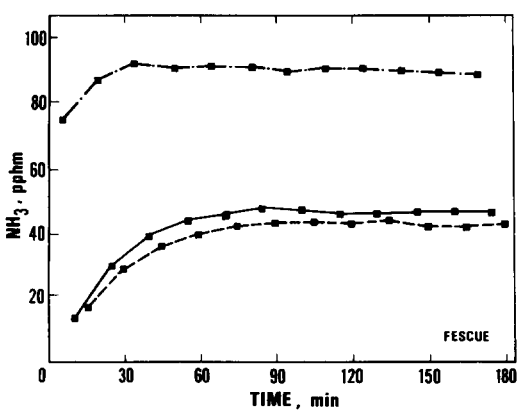

FIG. 2. Ammonia inlet concentration (—·—·) and outlet concentrations of the two chambers. One contained fescue with a total leaf area of 6.40 dm^2 (——) and the other contained fescue with a total leaf area of 7.32 dm^2 (— —). Actual instrument readings (■) at 15-min intervals.

Uptake rate by species

Differences in the NH_3 sorption rates among species are shown in (Table 1). This study confirmed similar results reported by ANEJA[1] who found corn to have the lowest and fescue the highest rate of NH_3 uptake. Comparisons of extremes suggest that total diffusion resistance is largely responsible for species differences although considerable variability is seen in this measure. For example, the mean rate of uptake for corn was 0.015 μg/dm^2/min/pphm; the rate for fescue was four times greater but its total diffusion resistance was only about one-fourth that of corn. In the two snap bean varieties which have similar plant size and architecture, there is an observable inverse relationship between NH_3 sorption rate and total diffusion resistance. HUTCHINSON *et al.*[9] suggested that NH_3 absorption rate differences among plant species are related to varying internal leaf geometry, which in turn governs the resistance to NH_3 diffusion across the internal air spaces.

Figure 3 is a plot of NH_3 absorption rate versus the inverse of total diffusion resistance ($1/R_{total}$). Values for the three bean types and the three grain types (fescue, wheat, and oats) were clustered. A regression line for all species except the bean types (these clustered independently from the other species) is given. Among these eight species, the graph shows a common relationship between the rate of NH_3 uptake and the reciprocal of total diffusion resistance.

Concentration

The rate of NH_3 sorption by BBL-290 snap bean increased with exposure concentration. However, the uptake rate did not seem to be a

Table 1. Ranking of NH_3 *sorption rates by species, number of experimental runs (N), average age, and mean ± S.E. of the mean for leaf area (4 plants), exposure concentration for* NH_3*, rate of* NH_3 *sorption and total diffusion resistance* R_{total} *(sec/cm); four plants were used in each experimental run*

Species	N	Age (days)	Leaf area (dm^2)	NH_3 conc. (pphm)	NH_3 sorption rate ($\mu g/dm^2/min/pphm$)	R_{total} (sec/cm)
Corn	4	18	6.3 ± 0.6	32.0 ± 2.4	0.015 ± 0.001	3.8 ± 0.2
Tobacco	4	41	5.4 ± 0.2	17.3 ± 0.8	0.026 ± 0.001	1.6 ± 0.1
Cotton	4	18	2.6 ± 0.1	33.1 ± 1.5	0.028 ± 0.001	1.7 ± 0.1
Tomato	4	27	4.6 ± 0.1	14.8 ± 0.8	0.043 ± 0.003	1.2 ± 0.0
Orchard grass	6	33	1.8 ± 0.0	28.3 ± 2.9	0.043 ± 0.007	1.6 ± 0.1
Soybean	4	21	6.1 ± 0.4	17.0 ± 1.5	0.046 ± 0.005	2.6 ± 0.4
Snap bean (BBL-274)	4	18	8.5 ± 1.5	14.0 ± 1.2	0.050 ± 0.009	3.3 ± 1.1
Oat	5	25	3.4 ± 0.1	20.0 ± 1.7	0.056 ± 0.006	1.0 ± 0.1
Snap bean (BBL-290)	4	18	6.2 ± 1.1	14.0 ± 1.8	0.058 ± 0.011	2.3 ± 0.7
Wheat	3	19	1.5 ± 0.2	27.7 ± 2.7	0.063 ± 0.002	1.0 ± 0.2
Fescue	8	28	1.1 ± 0.2	34.1 ± 4.1	0.064 ± 0.006	1.0 ± 0.1

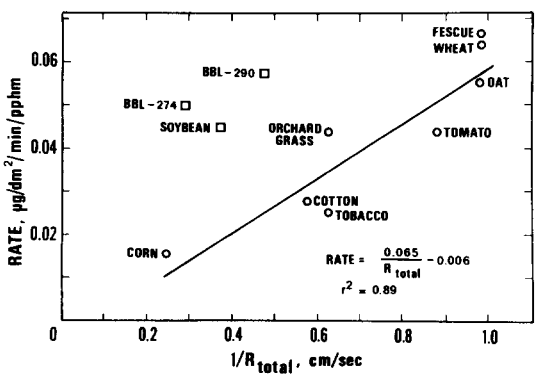

FIG. 3. Plot of means for rate of NH_3 sorption versus total diffusion resistance for all species tested. Regression was calculated for all species except beans (BBL-290, BBL-274, soybean).

first order function of concentration, but rather a complex mechanism. Data in Table 2 suggest that NH_3 may decrease stomatal resistance. This phenomenon has been hypothesized by WITTWER and ROBB[19] who suggested that NH_3 might be used to keep stomates open at elevated CO_2 levels. The small decrease in total diffusion resistance which accompanies the rise in uptake rate supports this suggestion. There was close agreement between replicates.

Table 2. Rate of NH_3 *uptake and total diffusion reistance* (R_{total}) *of* BBL-290 *snap bean at different levels of* NH_3*. Each value of the duplicate pairs is from a single experimental run*

NH_3 conc. (pphm)	NH_3 sorption rate ($\mu g/dm^2/min/pphm$)	R_{total} (sec/cm)
19	0.050	3.0
20	0.051	3.0
28	0.064	2.7
32	0.058	2.7
42	0.068	2.6
45	0.067	2.6

Tissue nitrogen

The N content of BBL-290 snap bean growth under four different nutrient regimes varied from 4.6 to 5.6% yielding leaf areas (per 4 plants) of 2.9–7.3 dm^2, but rates of NH_3 sorption among treatments were quite similar (Table 3). The four nitrogen regimes were set up by watering with nutrient solutions of varying N content.[5] Plants at lower N contents showed a reduction in leaf area and a general chlorosis. The conclusion that the N supply did

Table 3. Relationship of tissue N content, leaf area (4 plants), NH_3 sorption rate and total diffusion resistance (R_{total}) for BBL-290 snap bean

Tissue nitrogen (%)	Leaf area (dm^2)	NH_3 sorption rate ($\mu g/dm^2/min/pphm$)	R_{total} (sec/cm)
4.6	2.9	0.036	2.1
5.3	7.2	0.042	3.0
5.5	7.3	0.042	2.9
5.6	5.9	0.037	2.2

not significantly affect NH_3 uptake rate was similar to that of HUTCHINSON *et al.*[9] who reported that N fertility level caused little difference in the absorption of NH_3 by single seedlings of soybean. A similar result has also been obtained with NO_2.[16]

Light

When light was stepped through four levels, NH_3 uptake rate by BBL-290 snap bean increased with each step. This increase with light was closely correlated with the inverse of total diffusion resistance. A plot of the means from 2 replicate runs and the fitted linear regression equation is shown in Fig. 4. A similar correlation has been observed for NO_2 uptake by soybean and corn.[16] The relationship observed here indicates that NH_3 flux to vegetation in the field would be heavily influenced by solar radiation which governs the magnitude of the total diffusion resistance.[18] Even short term changes (e.g. cloud cover) or any stress that would affect resistance could alter NH_3 flux.

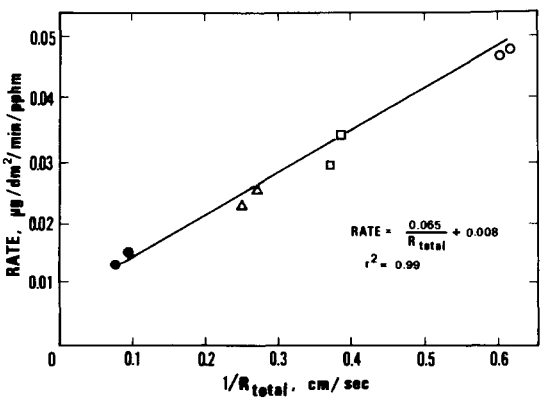

FIG. 4. Regression of the rate of NH_3 sorption on the reciprocal of total diffusion resistance ($1/R_{total}$) for snap bean at four PAR levels: 0(●), 73 (△), 146 (□), and 326 (○) μEinsteins/m^2/sec.

Repeated exposure

Whether the rate of NH_3 sorption by plants is altered through repeated exposure is an important consideration. Variation in the rate of sorption was not substantial over the test period (Table 4). Differences in rate were related to total diffusion resistance and variation in exposure concentration. The decrease in exposure concentration over the 7-day exposure period was a result of increased plant size which in turn increased the amount of NH_3 uptake. The inlet concentration was approximately 85 pphm in each of these exposures.

Table 4. Means of leaf area, NH_3 sorption rate and total diffusion resistance (R_{total}) for two groups of four BBL-290 snap bean plants exposed repeatedly to NH_3 for 7 days

Age (days)	Leaf area (dm^2)	NH_3 conc. (pphm)	NH_3 sorption rate ($\mu g/dm^2$/ min/pphm)	R_{total} (sec/cm)
11	2.8	23.3	0.061	1.6
12	3.1	24.0	0.053	1.6
13	3.8	22.5	0.048	1.8
14	4.5	19.8	0.049	2.8
15	5.0	15.5	0.060	1.9
16	6.1	15.5	0.045	1.8
17	7.1	14.8	0.042	2.3

Temperature

Using exposure temperatures of 22, 26 and 30°C, means for 2 replicates for sorption rate were 0.054, 0.059, and 0.060$\mu g/dm^2$/min/pphm and for total diffusion resistances of 2.8, 2.1, and 1.1 sec/cm. Ammonia concentration was held constant (15.7 ± 1.0 pphm) in the six experimental runs, showing that in the range tested, NH_3 sorption rate increased with an increase in temperature. This rate increase seemed to be attributable to decrease in total diffusion resistance.

In conclusion, the CSTR system can be used to dispense and monitor gaseous NH_3 in concentrations which resemble those found in the atmosphere. Plants have been shown to be a significant sink for atmospheric NH_3. The rates at which this sorption occurs is influenced by NH_3 concentration, light, and temperature, and there is an inverse relationship between NH_3 sorption rate and total diffusion resistance.

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