Atmospheric Ammonia: Absorption by Plant Leaves

Abstract. *By monitoring the disappearance of ammonia from an airstream flowing through a small growth chamber containing a single plant seedling, it was discovered that plant leaves absorb significant quantities of ammonia from the air, even at naturally occurring low atmospheric concentrations. The measured absorption rates of ammonia showed large diurnal fluctuations and varied somewhat among species, but differed little with the nitrogen fertility level of plants within a species.*

Because gaseous NH_3 is normally present in such small concentration in the atmosphere, interactions between atmospheric NH_3 and soil-water-plant systems have generally been considered of negligible importance. Recently, however, evidence contrary to this supposition has begun to accumulate. Malo and Purvis (*1*) observed that soils in New Jersey absorb sufficient NH_3 from the air to measurably increase their fertility. Hutchinson and Viets (*2*) demonstrated that the absorption of atmospheric NH_3 is probably the most important input of nitrogen into the surface waters of semiarid northeastern Colorado and provides enough nitrogen for lake eutrophication.

In the study reported here we found that plant leaves also act as a natural sink for atmospheric NH_3. Our data suggest that a field crop growing in air containing NH_3 at normal atmospheric concentrations might satisfy as much as 10 percent of its total nitrogen requirement by direct absorption of NH_3 from the air. We believe that the importance of atmospheric NH_3 as an agent for the transport and redistribution of nitrogen has been vastly underestimated.

There is some evidence that the NH_3 concentration of the earth's atmosphere has increased over the past century. In 1875 Schlossing (*3*) reported an average NH_3 content of 20 μg per cubic meter of air. Later estimates, cited by Eriksson (*4*), range from 7 to 87 μg of NH_3 per cubic meter of air, with both the mean and median estimates falling between 30 and 40 μg. Even more recently, Malo and Purvis (*1*) found, in weekly determinations made over a 12-month period, that the NH_3 content of the atmosphere at several locations in New Jersey averaged 57 μg per cubic meter of air, and values as high as 220 μg were recorded. Possible sources of the additional NH_3 include the combustion of coal and natural gas (*1*), auto exhaust (*5*), animal feed yards (*2*), agricultural fertilizers, municipal sewage treatment facilities, and the chemical industry. The ever-increasing sizes of these possible sources make it imperative that we more clearly define the interactions between atmospheric NH_3 and soil-water-plant systems.

Although it has been postulated that plants utilize small amounts of atmospheric NH_3 by the mechanism of soil absorption and subsequent root uptake, not until recently has the possibility of direct gaseous NH_3 exchange between plant leaves and the air received any serious consideration. Porter *et al.* (*6*) found ^{15}N-enriched nitrogen compounds in plants previously exposed to an atmosphere containing labeled NH_3. Since the soil supporting the plants was isolated from the enriched air, they concluded that direct foliar absorption was responsible, although they stipulated that simple isotopic exchange might have accounted for at least some of the apparent $[^{15}N]NH_3$ uptake.

Our objectives were as follows: (i) to demonstrate conclusively that plant leaves absorb NH_3 from the air and (ii) to estimate rates of absorption for different crop species. We followed the disappearance of NH_3 from a gas stream flowing through a small, externally lighted plant chamber containing a single plant seedling. The upper portion of the chamber, 15 cm in internal diameter and 30 cm tall, was constructed from two vertical concentric Lucite cylinders cemented at the top to a Lucite end plate and at the bottom to an annular Lucite flange. This flange was bolted to the flange of a similar, but inverted (10 cm in diameter by 10 cm tall) single-walled Lucite compartment which housed the soil container. A rubber O-ring between the two flanges sealed the entire enclosed space from external air, and the upper and lower compartments were divided by removable Lucite plates supplemented with commercially available ductseal around the plant stem. Cooling water (23°C) flowed through the 5-mm space between the cylindrical side walls of the upper chamber, and a small blade fan, blowing vertically downward from the top center of the chamber, kept the air inside adequately stirred. With this arrangement the inside air temperature was controlled at near 23°C at night and between 24° and 25°C under lights. Transpired water was carried away by the flowing gas stream. There was no air mixing or exchange in the lower compartment, but a small KOH trap prevented the buildup of CO_2 from root and soil respiration.

Two gas mixtures, one containing 500 parts per million NH_3 in N_2 and the other containing 1 percent CO_2 (by volume) in N_2, were metered into a stream of bottled, reconstituted air to provide 1 liter per minute of gas mixture having the desired CO_2 and NH_3 concentrations. This mixture passed through the plant chamber, through a gas dispersion tube into 0.1*N* KCl adjusted to a *p*H of 5.500 to remove NH_3, through $CaCl_2$ to remove water vapor, through an electronic flowmeter for monitoring total gas flow rate, and, finally, through an infrared analyzer for CO_2 analysis. Ammonia trapped in the KCl solution was periodically titrated to a potentiometric end point with 0.025*N* HCl, after the sample gas stream was diverted and dissolved CO_2 was removed by purging the solution with a stream of N_2. Black gum rubber tubing and polyethylene connectors were used for all air lines, because they sorbed much less NH_3 than other materials that were tested.

Single plants were germinated and grown under artificial light in plastic-coated paper cups (7 cm, bottom diameter; 9 cm, top diameter; 10 cm tall)

Table 1. Ammonia absorption rates for four crop species and for soybean at three nitrogen fertility levels.

Species	Added soil nitrogen (mg)	Leaf area (cm^2)	NH_3 in chamber air ($\mu g\ m^{-3}$)	NH_3 uptake rate ($\mu g\ dm^{-2}\ hr^{-1}$)
Soybean (*Glycine max*)	0	65	29	4.1
Soybean (*Glycine max*)	5	80	24	4.2
Soybean (*Glycine max*)	20	84	24	4.0
Sunflower (*Helianthus annuus*)	5	96	31	4.9
Corn (*Zea mays*)	5	58	24	5.6
Cotton (*Gossypium hirsutum*)	5	55	44	3.5

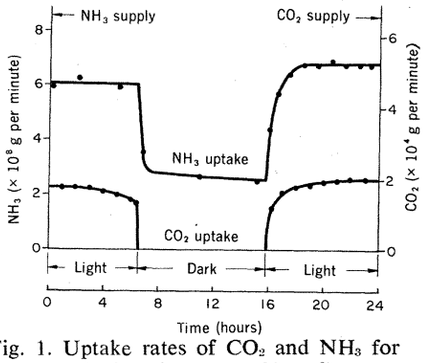

Fig. 1. Uptake rates of CO_2 and NH_3 for soybean (leaf surface area, 89 cm^2) growing in soil containing 5 mg of nitrogen as NH_4NO_3.

containing 308 g of sandy loam, 22 g of vermiculite, 33 mg of phosphorus as KH_2PO_4, 1.7 mg of iron as iron ethylenediamine di-(*o*-hydroxyphenyl acetate), 0.08 mg of boron as H_3BO_3, 3.3 mg of zinc as $ZnSO_4 \cdot 7H_2O$, 6.6 mg of sulfur as $ZnSO_4 \cdot 7H_2O$ and K_2SO_4, and variable amounts of nitrogen as NH_4NO_3. When the plants were about 15 cm tall, they were transferred to the Lucite chamber for measurement of CO_2 and NH_3 uptake rates. The uptake rates were estimated from the differences in the mass flows of CO_2 and NH_3 out of the chamber before and after the introduction of the plant, on the assumption that the composition of the gas mixture entering the chamber remained unchanged during the experiment. The total leaf surface area of the plants was estimated from tracings of the leaves on graph paper.

Data from a typical 24-hour trial are shown in Fig. 1. The NH_3 absorption rate was relatively constant during day 1 but dropped sharply at the beginning of the dark period, apparently reflecting the closing of the stomata. It is important to realize that, since the mass flow of NH_3 into the plant chamber remained constant, the lower absorption rate at night occurred in the presence of an NH_3 concentration about three times greater than the day concentration; thus the difference in day and night uptake rates is even more pronounced than is first apparent in Fig. 1. Immediately after the lights were turned on the following morning, the NH_3 absorption rate climbed rapidly and after 2 hours reached a plateau slightly higher than that which prevailed the preceding day. The higher uptake rate on day 2 is at least partially attributable to an overnight increase in the leaf surface area. The uptake of CO_2 followed a pattern similar to that of NH_3 except that the net uptake was, of course, negative during the dark period owing to the respiratory release of the gas.

The total amount of NH_3 absorbed by the soybean during the 24-hour period, about 70 μg, was nearly enough to saturate the amount of water contained in the plant, if its *p*H is 6.50. Therefore, the absence of any hint of NH_3 saturation in Fig. 1, along with the strong dependence of the uptake rate on stomatal opening, lends support to our contention that the absorbed NH_3 was metabolized rather than simply adsorbed onto exterior leaf surfaces or passively dissolved in the water bathing leaf mesophyll cells. Additional evidence is provided by Porter *et al.* (*6*), who found ^{15}N-enriched amides, amino acids, and proteins in plants previously exposed to labeled gaseous NH_3.

Table 1 compares NH_3 absorption rates for four crop species and for soybeans at three different nitrogen fertility levels. The data were taken from the absorption plateau roughly 4 to 8 hours after the initiation of the day cycle. Although the soybean plants not treated with nitrogen were visibly stunted and very chlorotic whereas those treated with 20 mg of nitrogen were very dark green and vigorous, these two classes of soybean plants showed no substantial differences in their NH_3 absorption rates on the basis of leaf area. Apparently, plants retain their capacity for absorbing NH_3 even when well supplied with nitrogen. There were some differences in the NH_3 absorption rates among species, cotton having the lowest rate and corn the highest. Although we have inadequate data for conclusive proof, we believe that these differences in absorption rates are explained entirely by species differences in internal leaf geometry, which in turn determines the resistance to diffusive transport of NH_3 across the air space inside leaves.

We believe that our data have broad implications in regard to both plant nutrition and air pollution and water pollution control. Calculations based on the data in Fig. 1 indicate that the annual NH_3 absorption by plant canopies could be about 20 kg per hectare. This rate of NH_3 supply is large enough to contribute significantly to the nitrogen budget of a growing plant community and could exert a prodigious influence on the long-term behavior of an ecosystem. Our data, together with data on the absorption of atmospheric SO_2 by plant leaves (*7*), also suggest an important role for plants in the decontamination of the earth's atmosphere.

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References and Notes

1. B. A. Malo and E. R. Purvis, *Soil Sci.* **97**, 242 (1964).
2. G. L. Hutchinson and F. G. Viets, Jr., *Science* **166**, 514 (1969).
3. T. Schlossing, *C. R. Hebd. Seances Acad. Sci. Paris* **80**, 175 (1875).
4. E. Eriksson, *Tellus* **4**, 215 (1952).
5. J. H. Harkins and S. W. Nicksic, *Environ. Sci. Technol.* **1**, 175 (1967).
6. L. K. Porter, F. G. Viets, Jr., G. L. Hutchinson, *Science* **175**, 759 (1972).
7. M. Fried, *Soil Sci. Soc. Amer. Proc.* **13**, 135 (1948).
8. This research was conducted in cooperation with the Illinois Agricultural Experimental Station.

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Evidence of Pollen Tubes in Paleozoic Pteridosperms

Abstract. *A saccate pollen grain with a branched pollen tube has been discovered within the pollen chamber of a fossil seed-fern ovule of Middle Pennsylvanian age. This suggests that microgametophytes comparable to those of living gymnosperms were produced by some Paleozoic pteridosperms.*

The pteridosperms are a remarkable group of fossil gymnospermous plants with fernlike leaves, cycad-like wood anatomy, and leaf-borne pollen organs. Paleozoic pteridosperms are traditionally divided into the polystelic medullosans and the monostelic lyginopterids. During microgametophyte formation these plants produced prepollen with proximally placed trilete or monolete