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Capture of Atmospheric Ammonium by Grassland Canopies

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Air pollution can cause a decline in species through acidification of the habitat. New data suggest that the decline may be due to eutrophication rather than acidification. In Western Europe, eutrophication largely results from atmospheric ammonium deposition. The amount deposited on vegetation is a function of its canopy structure. Deposition on grasslands has been underestimated, and a significant amount of the deposited ammonium appears to be assimilated by the plant canopy. These quantities are sufficient to initiate changes in the competitive relations among the plant species.

The two environmentally most damaging air pollutants in Western Europe are sulfur dioxide and ammonia or ammonium. They are deposited on surfaces at rates that vary with the structure of that surface. Forests were often shown to receive high amounts of air pollutants because of their rough canopy structure (*1*). Grasslands and croplands were thought to have rather smooth canopy structures and to capture much smaller amounts. Measurements inside grassland canopies are rare, however. Our data show that grassland canopies, depending on their structure, can capture as much air pollutants as forests.

Environmental acidification as a result of SO_2 pollution was shown to lead to declines in species abundance both in aquatic and terrestrial ecosystems, particularly in nutrient-poor sites (*2–4*). The main source for SO_2 is industry. Eutrophication largely results from atmospheric NH_x deposition, originating from the liquid manure used in great quantities in the intensive farming systems in Western Europe (*4–6*). Wind tunnel experiments have shown that the two pollutants are co-deposited (*7*). Amounts of bulk deposition (the sum of wet deposition and dry sedimentation) are relatively unaffected by the characteristics of the surfaces on which they are deposited, but amounts of dry deposition resulting from impaction, phoresis, and diffusion (*8*) are strongly determined by the roughness length of the deposition surface (*9*). Vegetation is the most widespread deposition surface. Forests have been shown to possess surface structures that highly promote deposition (*1, 10*). Deposition of pollutants on plant canopies is measured by comparing the composition of throughfall and bulk precipitation. So far, nearly all field measurements to correlate throughfall with canopy structure have been done in forests (*10, 11*) because it has proved difficult to measure in herbaceous vegetation without disturbing its canopy structure. Besides, herbaceous vegetation was presumed to have a relatively smooth canopy structure (*9*). However, forests cover only limited areas in the densely populated parts of Western Europe. In the Netherlands forests cover less than 9% of the country, whereas grasslands and croplands cover 70%. We investigated the effects of structurally different grassland canopies on deposition. In grasslands, leaf area index (LAI, the sum of the surface area of all leaves in a stand of vegetation per unit ground area) is correlated with other variables describing vegetation structure (*11, 12*).

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We developed a technique to measure throughfall in grassland canopies without disturbing the structure, using a system of slanting half-open channels (diameter 15 mm, capturing surface 165 cm^2) covered by polythene gauze (mesh size, 0.02 mm) to prevent contamination with litter and insects (*13*). Bulk deposition was measured above the vegetation. Bulk and throughfall precipitation were gathered in dark bottles dug in the ground to prevent chemical changes (*14*). Measurements were carried out in five replicates in each of two adjacent, homogenous grassland plots in a nature reserve amidst open agricultural land at Deil, about 30 km south of Utrecht, the Netherlands, from 15 June to 26 September 1986. During that period the plants grew up to a maximum of 80 cm. One plot was mown on 7 July to alter its canopy structure. The dark bottles were collected fortnightly. Samples were analyzed for SO_4^{2-} and NH_4^+ (spectrophotometrically, with a continous flow Skalar autoanalyzer). To measure canopy structure, once a month the vegetation was clipped at ground level in five replicate quadrates of 15 by 50 cm in each plot. In these samples LAI was determined with the use of a LiCor leaf area meter. Data were summarized for 28-day periods and statistically analyzed by analysis of variance (*15*). In the undisturbed plot, LAI increased until August and was lower again in September as leaves had started to die off (Table 1). The mown plot showed the same rhythm but LAI values obviously were much lower here during the growing season as a result of the mowing.

As reported previously for the Netherlands (*4*), the amount of SO_4^{2-} in bulk precipitation was linearly proportional to the amount of NH_4^+ (slope = 1.024 ± 0.149, n = 30, $P < 0.0001$, t test, df = 29). The amount of SO_4^{2-} in the throughfall of the mown grassland was equal to that in the bulk precipitation. In the undisturbed grassland, it was much higher when the LAI was high (Table 2). In both plots the amount of SO_4^{2-} in the throughfall expressed as a percentage of that in the bulk precipitation was linearly proportional with LAI (slope = 101.3 ± 17.9, n = 8, $P < 0.005$, t test, df = 7).

The amount of NH_4^+, on the other hand, was lower in the throughfall of both grasslands than in the bulk precipitation ($P < 0.001$) (Table 3). This is explained by the canopy exchange of NH_4^+ for other cations, such as K^+ and H^+ (*1, 16*).

The effect of the structure of a grassland canopy (here LAI) on the amounts of air pollutants deposited is clearly demonstrated: depending on structural development the amounts can differ by a factor 5.5. The total deposition of SO_4^{2-} on our undisturbed grassland during a summer season (3.5 months) amounted to 17.8 kg ha^{-1}. This value is similar to those predicted from atmospheric deposition models (*17*). It is as high as measured in the densely forested areas of the Netherlands (*4*). In the mown plot the total deposition of SO_4^{2-} is 7.6 kg ha^{-1}. Since NH_x proved to be co-deposited, we calculate the total deposition of NH_x during this period in the undisturbed grassland at 5.9 kg ha^{-1}. This value is similar to the most recent estimate based on density data for domestic animals (*6*). In the mown plot the calculated value is 2.5 kg ha^{-1}.

Laboratory experiments have shown that while SO_4^{2-} is not assimilated by plant canopies, NH_4^+ is (*18*). The difference between the calculated and measured throughfall values for NH_4^+ must have been assimilated by the canopy. This difference in the mown grassland canopy is 1.2 kg ha^{-1} during the 3.5-month growing season; in the undisturbed grassland canopy, it is 4.7 kg ha^{-1}. Heil (*19*) showed that smaller increases in NH_4^+ availability were already sufficient to change the competitive relations between species: in a competition experiment on nutrient-poor soil, fast-growing species (*Molinia caerulea* and *Festuca ovina*) benefited more from slightly raised ammonia levels and gradually outcompeted the slow-growing species (*Calluna vulgaris*). Earlier a statistically significant correlation was observed between the amount of SO_2 pollution in the air and the decline in abundance of a number of slow-growing plant species of nutrient-poor sites in the Netherlands (*3*). It was stated that the decline was caused by acidification of the environment. Our measurements and experiments suggest that the decline was caused by eutrophication and the subsequent competitive exclusion of those slow-growing species.

Table 1. Leaf area index (LAI) of grasslands. Values are means of five measurements. Numbers in parentheses are standard deviations.

Month	LAI (m^2/m^2) Undisturbed grassland	LAI (m^2/m^2) Mown grassland
June	3.2 (± 0.7)	3.2 (± 0.7)
July	4.6 (± 1.6)	1.8 (± 0.6)
August	5.7 (± 1.0)	3.2 (± 0.7)
September	2.0 (± 0.7)	1.9 (± 0.5)

Table 2. Sulfate deposition in bulk and throughfall precipitation. Values are means of five measurements. Numbers in parentheses are standard deviations.

Month	Bulk (kg ha^{-1})	Throughfall			
		Undisturbed grassland		Mown grassland	
		Kilogram/ hectare	Percentage of bulk	Kilogram/ hectare	Percentage of bulk
June*	0.67 (± 0.16)	1.30 (± 0.14)	194	1.22 (± 0.25)	182
July	3.07 (± 0.69)	7.98 (± 0.83)	260	3.31 (± 0.12)	108
August	1.22 (± 0.78)	6.73 (± 2.08)	552	1.55 (± 0.26)	128
September	1.67 (± 0.82)	1.76 (± 1.36)	105	1.53 (± 0.18)	92
Total	6.63	17.77	268	7.61	115

*June data are measured over a 14-day period.

Table 3. Ammonium deposition in bulk and throughfall precipitation. Values are means of five measurements. Numbers in parentheses are standard deviations.

Month	Bulk (kg ha^{-1})	Throughfall			
		Undisturbed grassland		Mown grassland	
		Kilogram/ hectare	Percentage of bulk	Kilogram/ hectare	Percentage of bulk
June*	0.16 (± 0.03)	0.14 (± 0.03)	86	0.12 (± 0.03)	75
July	0.94 (± 0.31)	0.79 (± 0.65)	84	0.73 (± 0.09)	78
August	0.58 (± 0.28)	0.11 (± 0.06)	19	0.22 (± 0.02)	38
September	0.53 (± 0.18)	0.21 (± 0.05)	40	0.33 (± 0.05)	63
Total	2.21	1.25	54	1.40	63

*June data are measured over a 14-day period.

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