ELEMENT FLUX IN A DECIDUOUS FOREST EXPOSED TO AIR POLLUTION

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Abstract.--Element inputs in precipitation and transfers in throughfall and soil leachate beneath yellow buckeye (*Aesculus octandra* Marsh.) canopies were compared in mixed mesophytic forest stands in a heavily industrialized region and an area relatively remote from air pollutant sources within the Ohio River Valley in southeastern Ohio USA. Atmospheric deposition of cations (Ca^{+2}, Mg^{+2}) and anions (NO_3^-, SO_4^{-2}, Cl^-, F^-) was generally greater in the high air pollutant exposure (HE) forest than in the low exposure (LE) stand, and was generally greater than that reported for less-polluted regions. Incident rainfall was relatively high in pH at both sites (4.9 and 5.2, HE and LE, respectively), and was strongly buffered by the canopy and soil. Throughfall was enriched in concentrations of all ions over incident precipitation. Calcium, Cl^- and F^- throughfall fluxes were significantly greater in the HE stand, and these same ions, in additon to SO_4^{-2}, had greater flux rates through the surface soil of the HE stand. The rapid transfer rates associated with increasing air pollutant exposure could place forests in the high exposure area at greater risk of nutrient depletion, especially following major vegetation impoverishment. However, greater incident fluxes of pollutant-associated macronutrients into such areas may tend to buffer the ecosystem against excessive element losses and reduce the time required to re-establish a steady state.

Additional keywords: Air pollution, atmospheric deposition, throughfall, nutrient cycling.

INTRODUCTION

Natural forest ecosystems generally depend upon nutrient cycling to maintain a given level of functioning. Element inputs to the system occur as wet and dry atmospheric depostion and geochemical weathering. Perturbations in the element budget resulting from air pollutant inputs may potentially alter biomass production, succession, or other aspects of community functioning.

Anthropogenic sources of airborne elements are added to the forest ecosystem through vegetative filtration of particles, aerosols, and gases, and in wet and dry precipitation. Acid precipitation resulting from certain pollutant emissions may further affect the internal cycling of elements through such processes as accelerated rates of geochemical weathering, increased leaching losses from vegetation, and altered soil biotic activity. Depending upon the nature and quantity of elements added, the potential exists for enrichment of

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the nutrient pool, as well as for toxic effects on the ecosystem.

Knowledge is presently limited regarding the influence of industrial air emissions on element input and movement in forest ecosystems, and the ultimate impact in terms of community structure and functioning. A previous study reported changes in diversity, structure and composition of forest communities on similar sites along an industrial air pollutant gradient in the Ohio River Valley (McClenahen, 1978). The objective of the present study was to compare certain aspects of element cycling on sites representing extremes of high and low air pollutant exposure on this same gradient.

METHODS

Data were collected within two mixed mesophytic forest stands (∿3ha) representing extremes of pollutant exposures along an air pollutant gradient within the Ohio River Valley in southeastern Ohio. This portion of the Ohio River flows southerly and lies in a narrow 150 to 200-m deep valley within the Allegheny Plateau. Two coal-fired power plants, two chemical plants, and an aluminum reduction facility are concentrated in the northern part of the study area within the valley, and vary from 1 km south to 14 km north of the high air pollutant exposure (HE) stand. The low exposure (LE) stand was 24 km south (downriver) of the high exposure stand and 14 km north of the nearest air emissions source, a chemical plant. Major known air emissions in the study area include F^-, Cl^-, SO_x, and NO_x. There is a decreasing air pollutant gradient from the vicinity of the HE stand southward to the LE stand. (McClenahen, 1978).

Details of the forest type, air pollutant sources, and effects of air pollutants on the forest community have been reported for this part of the Ohio Valley (McClenahen, 1978). The two stands in the present study were located on mid- and lower north-facing slopes within narrow draws on the west slope of the main valley. Soils were of the Gilpin and Upshur series; both are deep, well-drained silt loams which intergrade on these steep slopes (Table 1). Species were typical of the mixed mesophytic type (Braun, 1950), but differed markedly in richness and relative species proportions between stands despite the similarity of the two sites (Table 2). This contrast in vegetation is attributed to differential air pollution exposure beginning in the early 1940's (McClenahen, 1978).

Wet plus dry precipitation was collected in an open area adjacent to each stand (2 collectors/stand). For comparison, precipitation was also collected at our laboratory at Wooster, Ohio. Wooster has a population of about 19,000. There are numerous manufacturing concerns and a few light industries in the area, including several coal-fired institutional heating plants. Throughfall was sampled at two points beneath the crowns of each of two yellow buckeye (*Aesculus octandra* Marsh.) trees per stand (4 collectors/stand). Collectors consisted of polyethylene funnels and bottles. Glass wool was used in the funnels to filter large debris.

Soil leachate was sampled at 15 cm depth by placing one 0.93 m^2 wooden lysimeter box beneath the crown of each sample tree (2/stand). The lysimeters were kept free of plant growth. Throughfall and soil leachate collection was restricted to the crown areas of a common species, yellow buckeye, to minimize sampling variation.

Table 1. Results of chemical analyses of surface 15 cm of soils from forest sites exposed to high and low air pollutant levels.

Analysis	High Exposure	Low Exposure
pH	5.8	5.4
Exchangeable Cations		
K, ppm	192	128
Ca, ppm	3587	2270
Mg, ppm	234	268
Cation Exchange Capacity, me/100g	28.3	23.3
Percent Base Saturation		
K	1.7	1.4
Ca	63.7	48.7
Mg	6.7	9.3

The collected volumes were retrieved bi-monthly or more often as necsssary, filtered (Whatman No. 41), and aliquots for the various analyses were preserved according to USEPA guidelines (Methods for Chemical Analyses of Water and Waste, 1974). Each collection was analyzed for K^+, Ca^{+2}, Mg^{+2} (atomic absorption), SO_4^{-2} (barium sulfate turbidometric method), NO_3^- + NO_2^- -N (cadmium reduction-spectrophotometer method), Cl^- (Buchler-Cotlove Chloridometer), and F^- (ion specific F^- electrode). Thirteen separate collections were made during the period May 24-December 6, 1978.

RESULTS AND DISCUSSION

Precipitation

Total rainfall at the high pollutant exposure (HE) stand slightly exceeded that at the low exposure (LE) stand (61.9 and 58.9 cm, respectively). Wooster received 50.7 cm during the same 197-day sample period. Along with a decreasing gradient of rainfall, concentrations and total atmospheric inputs of most elements also decreased from the HE and LE stands to the Wooster site (Tables 3 and 4). The HE stand consistently received greater atmospheric deposition and had higher transfer rates for all elements except K^+ and Mg^{+2} than the LE stand (Tables 3 and 4). The fact that inputs at Wooster were below those of either site for all elements except NO_3^- further indicates that atmospheric deposition at the LE site was also affected by the air pollutant sources.

Precipitation input of SO_4^{-2} was not greatly different between forest sites despite SO_2 emissions sources near the HE stand. Both sites received much higher inputs of SO_4^{-2} than reported for North Dakota (Killingbeck and Wali, 1978), Iowa (Tabatabai and Laflen, 1976), Walker Branch in Tennessee (Shriner and Henderson, 1978), southern Illinois (Weaver and Brown, 1979), or Hubbard Brook

Table 2.--Comparison of forest community composition between stands subjected to high or low air pollutant exposure.

Stratum/Species	Stand: High Exposure	Stand: Low Exposure
OVERSTORY[a]	-no. stems/ha-	
Aesculus octandra Marsh.	350	100
Acer saccharum Marsh.	-0-	50
Tilia americana L.	-0-	83
Liriodendron tulipifera L.	-0-	17
Other	34	51
Total	384	301
SUBCANOPY[b]		
Aesculus octandra Marsh.	183	100
Acer saccharum Marsh.	17	150
Tilia americana L.	-0-	100
Liriodendron tulipifera L.	-0-	83
Cornus florida L.	-0-	83
Lindera benzoin (L.) Bl.	250	33
Asimina triloba (L.) Dunal	250	-0-
Other	17	218
Total	717	767
SHRUB[c]		
Aesculus octandra Marsh.	94	56
Acer saccharum Marsh.	62	1,917
Lindera benzoin (L.) Bl.	3,500	2,972
Fraxinus americana L.	94	222
Asimina triloba (L.) Dunal	969	417
Hydrangea arborescens L.	1,906	-0-
Other	406	696
Total	7,031	6,280
TOTAL SPECIES	-number-	
Overstory	3	7
Subcanopy	5	13
Shrub	8	16

a/ Trees ≥15 cm diameter at breast height (1.4m). Means based on six .01 ha circular quadrats.

b/ Woody stems <15 and ≥2.5 cm diameter at breast height. Means based on six .01 ha circular quadrats.

c/ Woody stems <2.5 cm diameter at breast height. Means based on eighteen and sixteen .002 ha circular quadrats in the high and low exposure stands, respectively.

Table 3. Average concentrations of elements in rain, throughfall and soil leachate at Wooster and at forest sites exposed to high and low air pollutant emissions.

Type/Site	Element[a]						
	NO_3^-	K^+	Ca^{+2}	Mg^{+2}	SO_4^{-2}	Cl^-	F^-
	-mg/l-						
PRECIPITATION							
High	0.44	0.8	2.6	0.31	9.3	0.4	1.43
Low	0.31	1.8	1.6	0.36	8.2	0.3	0.10
Wooster	0.36	0.3	0.9	0.13	3.8	0.01	0.02
THROUGHFALL							
High	0.67	8.8	8.1	1.46	22.1	3.4	1.73
Low	0.54	11.7	5.5	1.15	19.6	0.9	0.33
SOIL LEACHATE							
High	18.9	7.9	25.6	2.83	33.4	6.0	1.01
Low	15.9	5.8	18.1	3.45	27.1	2.3	0.23

a/ Averages based on 197-day measurement period (May 24 to December 6, 1978).

Table 4. Average element flux and pH at Wooster and at high and low air pollutant exposure sites in the Ohio River Valley[a].

Type/Site	pH	NO_3^-	K^+	Ca^{+2}	Mg^{+2}	SO_4^{-2}	Cl^-	F^-
PRECIPITATION	-units-				-mg/m^2/month-			
High	4.9	47	70	209	28	831	39	123
Low	5.2	27*	143	130	29	732	28	8*
Wooster	4.4	44	32	112	16	459	2	2
THROUGHFALL[b]								
High	5.9	45	484	441	79	1208	195	102
Low	6.0	34	680	297*	65	1063	60*	19*
SOIL LEACHATE								
High	7.3	661	178	991	63	769	140	24
Low	7.0*	281	100	291*	57	400*	38*	4*

a/ Based on 197-day measurement period (May 24 to December 6, 1978).

b/ Estimates are low due to overflow of sample collectors on several occasions.

* Significant difference between Ohio River Valley sites (P = 0.05).

in New Hampshire (Whittaker et al., 1979). Sulfate input at Wooster closely agreed with that at Walker Branch (Shriner and Henderson, 1978), but was considerablely greater than reported by the other investigators. As at Walker Branch, SO_4^{-2} depostion at Wooster was apparently influenced by local (and perhaps also remote) coal combustion emissions.

Atmospheric NO_3^- deposition at the HE site predictably exceeded that at the LE site (Tables 3 and 4); an NO_x emissions source lay 2 km east of the HE stand. However, NO_3^- deposition at all three locations fell within the range of values reported elsewhere (Tabatabai and Laflen, 1976; Killingbeck and Wali, 1978; Whittaker et al., 1979).

Chloride deposition at Wooster was low and quite similar to that measured in North Dakota (Killingbeck and Wali, 1978). The two forest sites did not differ greatly in Cl^- input, but their inputs were about 15X that at Wooster (Tables 3 and 4). High atmospheric Cl^- deposition at both forest sites can be attributed to multiple Cl^- air emissions sources in this portion of the Ohio River Valley (McClenahen, 1978).

Wooster rain was low in F^- compared to some industrial areas (Garber, 1970). Emissions from an aluminum reduction plant seemed to slightly elevate F^- inputs to the LE forest site and grossly increased F^- deposition at the HE stand. Both up-and down-valley F^- transport has been substantiated (McClenahen and Weidensaul, 1977). The highest F^- concentration in a collection period (21 days) was 3.5 mg/l at the HE stand; the lowest value at this site was 0.52 mg/l. The range in F^- values at the LE site was 0.02 to 0.13 mg/l. Garber (1970) reported F^- concentrations in rain for industrial regions of Germany ranging from 0.28 to 14.1 mg/l.

Atmospheric deposition of cations (K^+, Ca^{+2}, Mg^{+2}) was greater at the forest sites than at Wooster (Table 4), and inputs at all sites were generally greater than those for non-industrial regions (Likens et al., 1967; Killingbeck and Wali, 1978; Rolfe et al., 1978). This seems to indicate some nutrient enrichment, particularly of the forest sites, associated with air pollutant emissions. Although the differences were not significant, the LE stand tended to receive greater total K^+ inputs than the HE stand, whereas the HE stand tended to receive more Ca^{+2}. Precipitation inputs relating to air emissions (SO_4^{-2}, Cl^-, F^- and NO_3^-) were positively and nearly all significantly correlated between the HE and the LE sites (Table 5). This further confirms the influence of air emissions sources on deposition at both forest sites. Emissions of Cl^- and NO_x from common locations (viz., two chemical plants) were also substantiated by significant correlations between Cl^- and NO_3^- both within and between sites (Tables 5 and 6). On the other hand, these same correlations for Cl^- and F^- were quite low, a reflection of their separate source locations. Thus, some discrimination of the respective impacts of pollutant sources on element deposition was possible. This demonstrates the potential use of precipitation quality as an alternative to air monitoring to determine areas being affected by particular air pollutant sources or air pollutant types.

High cation intracorrelations show these inputs are strongly associated at each forest site, but usually not at Wooster (Table 6). Conversely, poor between-site correlations for cations (Table 5) indicate that factors different from those governing pollutant deposition affected inputs of K^+, Ca^{+2} and Mg^{+2}. However, SO_4^{-2} input at the HE site was highly and positively correlated with K^+ and Ca^{+2} inputs at the LE site. Significant, positive correlations also

Table 5. Correlations of total element deposition between sites subject to high and low air pollutant exposure.

High Exposure Site	Low Exposure Site							
	NO_3^-	SO_4^{-2}	K^+	Ca^{+2}	Mg^{+2}	Cl^-	F^-	pH
	-Precipitation-							
NO_3^-	.544	.652*	.282	.378	.103	.679	.199	.403
SO_4^{-2}	.534	.844*	.552*	.620*	.251	.664*	.232	.581*
K^+	-.160	.075	-.050	.270	-.044	-.258	-.114	-.158
Ca^{+2}	.214	.208	.037	.214	.133	-.018	.076	.000
Mg^{+2}	.209	.278	.094	.333	.153	.110	.101	-.034
Cl^-	.657*	.303	.115	.059	.123	.859*	.149	.066
F^-	.158	.310	.372	.439	.524	.001	.587*	.185
pH	-.326	-.246	-.250	-.324	-.461	-.375	-.588*	-.006

* Significant at P = 0.5, n = 13.

Table 6. Correlations of element deposition at forest sites subject to high (HE) and low (LE) air pollutant exposure, and at Wooster.

Plot		SO_4^{-2}	Cl^-	F^-	NO_3^-	Ca^{+2}	Mg^{+2}	K^+
Cl^-	HE	.443	-	-	-	-	-	-
	LE	.589*	-	-	-	-	-	-
	Wooster	-	-	-	-	-	-	-
F^-	HE	.478	.041	-	-	-	-	-
	LE	.275	.034	-	-	-	-	-
	Wooster	-	-	-	-	-	-	-
NO_3^-	HE	.614*	.536*	.335	-	-	-	-
	LE	.401	.628*	-.127	-	-	-	-
	Wooster	.430	-	-	-	-	-	-
Ca^{+2}	HE	.475	.062	.423	.112	-	-	-
	LE	.786*	.320	.583*	-.079	-	-	-
	Wooster	.505	-	-	.735*	-	-	-
Mg^{+2}	HE	.532	.141	.463	.213	.971*	-	-
	LE	.298	.016	.968	-.236	.638*	-	-
	Wooster	.612	-	-	.513	.919*	-	-
K^+	HE	.178	-.315	.261	-.105	.807*	.834*	-
	LE	.758*	.269	.628*	-.102	.860*	.724*	-
	Wooster	-.735*	-	-	-.293	-.450	-.628	-
pH	HE	-.327	-.436	-.502	-.571*	-.034	-.128	.234
	LE	.760*	.312	.177	.370	.511	.200	.587*
	Wooster	.109	-	-	-.086	-.198	-.067	-.349

* Sig. @ P = .05; n = 13 for forest sites, n = 8 for Wooster.

Note: Correlations for Cl^- and F^- at Wooster were not computed because observations were mostly zero (Cl^-) or were essentially constant (F^-).

occurred between F^- and K^+, Ca^{+2} and Mg^{+2} at the LE stand (Table 6). These relationships suggest that cation inputs partially originated from one or more of the air emissions sources. Coal combustion emissions could be one such source. Coal in this region averages 0.14, 0.23 and 0.062 percent K^+, Ca^{+2} and Mg^{+2}, respectively (Botoman and Stith, 1978).

Rainfall in this portion of the Ohio River Valley was not particularly acidic compared with the northeastern U.S. (Likens and Bormann, 1974) or Tennessee (Shriner and Henderson, 1978), but was more acid than that reported for Iowa (Tabatabai and Laflen, 1976)(Table 4).

Precipitation at Wooster was lower in pH than that in the industrialized Ohio River Valley, and lower at the HE site than at the LE site. Monthly input of bases (Ca^{+2}, Mg^{+2}, K^+) averaged 14.5 me m^{-2} at the HE stand and 12.5 me m^{-2} at the LE stand. Assuming all Cl^-, F^-, NO_3^- and SO_4^{-2} inputs were in acid components yields 25.7 and 16.8 me m^{-2} for the respective stands. Thus, the total equivalent cations nearly balanced the potential acid anion components of rain at the LE site. However, the proportions of NO_3^- and SO_4^{-2} reaching these sites as NH_4^+ salts is not known, but could be significant (Tabatabai and Laflen, 1976).

At the LE site, SO_4^{-2} content of rain strongly and postively correlated with pH and amounts of $Ca^{+2}$and K^+ (Table 5), which suggest that SO_4^{-2} input may have been largely as salts of these bases. A similar trend was not evident for the HE site and, in fact, the negative correlations of SO_4^{-2}, NO_3^-, Cl^- and F^- with pH indicate a more substantial portion of these ions may have been acid components.

Throughfall

Rainfall increased in concentrations of all elements after passage through the canopy of yellow buckeye (Table 3). Ion flux in throughfall tended to be greatest in the HE stand, especially for Ca^{+2}, Cl^- and F^- (Table 4). Net enrichment of throughfall during the growing season is typical for most elements (Killingbeck and Wali, 1978; Rolfe et al., 1978; Mayer and Ulrich, 1977, 1978); however, net canopy retention of Cl^-, SO_4^{-2}, and NO_3^- has been reported in areas remote from industrial air pollution (Killingbeck and Wali, 1978; Weaver and Brown, 1979). In this study, there was apparent net canopy retention of F^- and perhaps NO_3^- in the HE but not the LE stand (Table 4), which can be only partly attributed to the underestimate of throughfall volume resulting from occasional collector overflow. Throughfall flux for NO_3^-, SO_4^{-2} and the cations in both stands exceeded rates given for some other forests (Rolfe, et al., 1978; Killingbeck and Wali, 1978; Johnson and Risser, 1974; Reiners, 1972), although SO_4^{-2} flux was slightly less than that reported by Shriner and Henderson (1978).

The contribution of canopy SO_4^{-2} to throughfall in both stands was proportional to the amount of SO_4^{-2} received in precipitation (Table 4). This appeared generally to be the case for NO_3^-, Ca^{+2}, and Mg^{+2}, but not for K^+, Cl^- and F^-. The canopy increased the Cl^- transfer of throughfall 5X in the HE stand, but only 2X in the LE stand. Chloride concentrations in yellow buckeye foliage averaged 0.12 and 0.05 percent in the HE and LE stands, respectively. The quantity of leaf Cl^- removed by rain in the HE stand increased disproportionately over that accumulated by foliage, which may have resulted from greater atmospheric Cl^- deposition on leaves in this stand.

The apparent net canopy retention of F^- in only the HE stand is puzzling. Highest incident F^- input occurred at the HE site, and yellow buckeye leaves in the HE stand averaged 9 X higher F^- concentrations than those in the LE stand (120 ppm and 13 ppm, respectively). Despite this, the canopy of the LE stand increased net F^- transfer to the soil 2.4X (Table 4). The literature indicates that F^- is readily washed from foliage (Knabe, 1970; Jacobson et al., 1966). Possibly, F^- was more strongly retained in leaves in the HE stand as a result of pollutant-associated materials accumulated by foliage.

Rainfall acidity was reduced by passage through the forest canopy to the extent that pH of throughfall was raised about one unit at both sites (Table 4). This buffering capacity of the canopy can be expected to largely disappear after leaf fall; however, data in this study were insufficient to reflect such trends. It is significant that the different magnitudes of industrial air pollutant exposure did not alter the buffering capacity of yellow buckeye foliage. Reductions in throughfall pH compared with incident precipitation have been reported beneath beech and spruce in other industrialized regions (Baker et al., 1976; Mayer and Ulrich, 1977).

Soil Leachate

Regardless of pollutant exposure, water passing through the top 15 cm of soil increased in concentration of most ions except K^+ over levels in throughfall (Table 3). However, flux values indicate an apparent net retention of all ions except NO_3^- and Ca^{+2} in soils of both stands over the period monitored (Table 4). Rates of ion flux from surface soil were significantly greater in the HE than the LE stand for Ca^{+2}, SO_4^{-2}, Cl^-, and F^-, and there was more than a two-fold difference for NO_3^-. The HE stand therefore seems to be at greater inherent risk of nutrient depletion,; however, the available data do not indicate that this has occurred.

The large cation flux and favorable pH and cation exchange capacities (Table 1) exhibited by soils at both levels of pollutant exposure, and particularly the dominance of Ca^{+2} and SO_4^{-2} in soil leachate, indicate these soils have considerable buffering capacity (Likens et al., 1977). Although the data do not represent annual surface soil leachate losses, especially those occurring in winter when potential losses are greatest, the large precipitation inputs and inherently high cation retention capacity of the soil further suggest that air pollutant impacts on soil acidification and nutrient depletion has been minimal on these sites. In fact, general nutrient enrichment of the HE and perhaps the LE stand has probably occurred as part of the deposition from industrial air emissions in this region. This may not be true for NO_3^-, however. Considerable quantities of this ion were found in soil leachate. These amounts represent leaching plus plant uptake because the lysimeter boxes were vegetation-free. However, a relatively larger NO_3^- loss occurred in the HE stand, perhaps partly due to a faster rate of litter decomposition on this site (Van-Fossen and McClenahen, unpublished data). Accelerated litter breakdown is thought to be due in part to air pollutant-induced changes in community structure leading in turn to an understory microclimate more favorable for litter decomposition (McClenahen, 1978). Regardless, the HE site appears more susceptible to NO_3^- depletion, although the role, if any, of air pollution in this process is unclear.

Fluoride is ordinarily strongly adsorbed by clay-containing soils in forms largely unavailable to plants (Larsen and Widdowson, 1971; Bower and Hatcher,

1967). However, the significantly greater quantity of leachate F^- in the HE stand (Table 4) could serve as an important secondary F^- source for plants on this site.

Unlike F^-, a large amount of Cl^- is apparently available for plant uptake or leaching loss, especially in the HE stand (Table 4).

CONCLUSIONS

Atmospheric deposition in forests within this portion of the Ohio River Valley is strongly influenced by industrial air emissions. The possibility cannot be ruled out that the magnitude of certain ion inputs (viz. SO_4^{-2}, Cl^-, F^-) could induce dysfunctions in nutrient element cycling or accrue to toxic levels in the ecosystem. For example, sugar maple (Acer saccharum Marsh.) appears especially sensitive to airborne Cl^- (McClenahen, 1978; Lacasse and Treshow, 1976), and the particular reduction in importance of this species may have been compounded by additional Cl^- exposure through atmospheric deposition and a high rate of mobility in the internal element cycle.

Greater atmospheric deposition and internal transfer of macronutrients were also associated with increasing air pollutant exposure. It is possible this nutrient enrichment of the ecosystem tends to offset harmful pollutant effects, although the limited evidence available suggests greater plant sensitivity to gaseous pollutants under nutrient-rich conditions (Lacasse and Treshow, 1976). The high nutrient deposition rates associated with increasing pollutant exposure may also serve to buffer the system against element losses which might occur as a result of pollutant-induced vegetation changes. (McClenahen, 1978).

The observed changes in the forest communities are probably largely a result of direct airborne pollutant impact on vegetation. However, added stresses imposed by toxic amounts or types of pollutant-related elements such as Cl^- in the internal element cycle seem plausable. A clearer understanding is needed concerning the forms in which pollutant and other ions enter the internal cycle, the amounts of elements contributed to internal cycling via direct plant and soil scavenging from the atmosphere, and finally, the stresses induced by various types and amounts of pollutant elements after entering the internal cycle.

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