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## INFLUENCE OF LEAF AREA ON ATMOSPHERIC INPUT OF ELEMENTS TO THE ECOSYSTEMS OF THE KAMPINOS NATIONAL PARK (CENTRAL POLAND)

**ABSTRACT:** The study was conducted in the buffer zone of the Kampinos National Park 30 km north from Warsaw in the growing seasons (April–October) of 1997–1999. In addition to element input into common rain collectors, their aerosol-gaseous input was determined, using collectors with artificial leaves of known surface areas – 2, 6, and 12 m<sup>2</sup> m<sup>-2</sup>. It was found that the input of the majority of elements markedly increased with increasing artificial leaf area (Na<sup>+</sup>, N-NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>, N-NO<sub>3</sub><sup>-</sup>, S-SO<sub>4</sub><sup>2-</sup>, P-PO<sub>4</sub><sup>3-</sup>, and less intensively Cd<sup>2+</sup> and Cu<sup>2+</sup>). This was not the case of H<sup>+</sup>, Zn<sup>2+</sup>, Pb<sup>2+</sup>, and atmospheric input of water. Proportional increase in anions and cations neutralising them accompanied increasing artificial leaf area, so that water acidity was stable. As a result of parallel increases in the input of most elements with increasing leaf area proportions between elements were maintained at fairly the same level in leaf area gradient.

**KEY WORDS:** atmospheric input of elements, macroelements, heavy metals, artificial leaves

### 1. INTRODUCTION

Problems concerning the atmospheric input of elements into different ecosystems are essential for plant nutrient uptake, and also in the context of the estimation of environmental conditions, thus they have been frequently examined (Westman 1978, Lovett and Kinsman 1990, Martin *et al.* 2000, Van Leeuwen *et al.* 2000). It has

been found that the atmospheric input to forest ecosystems is even several times higher than to areas without vegetation (Ross and Lindberg 1994, Stachurski and Zimka 2000). This is an effect of intensive capturing of aerosols and gases by forest canopies (Mayer and Ulrich 1977, Hosker and Lindberg 1982, Ragsdale *et al.* 1992). The loadings of ions reaching ecosystems in that way constitute a substantial fraction of the total element input (Lovett *et al.* 1985, Lovett and Lindberg 1993). It appears that different elements are captured with various intensities. The process of capturing is most efficient for sulphur and nitrogen compounds, and much less pronounced for cations of heavy metals (Lovett and Lindberg 1984, Stachurski and Zimka 2000). Foliage area seems to be of greatest importance to the magnitude of element interception. Also very important factors are humidity, temperature, location in forest canopy, or the concentration of ions in the air (Tjepkema *et al.* 1981, van Hove *et al.* 1989, Lovett and Lindberg 1992, Neal *et al.* 1994). Experiments with artificial foliage showed that the atmospheric input of elements increased with foliage area. This was especially true for nitrogen, sulphur, and also ions H<sup>+</sup> and Pb<sup>2+</sup>. Also proportions between elements varied with leaf area, e.g. nitrogen input increased with increasing foliage area at a higher rate than phosphorus or potassium inputs (Stachurski and Zimka 2000).



The objective of this study was to estimate the atmospheric input of elements to ecosystems in the buffer zone of the Kampinos National Park, including their deposition in gaseous and aerosol forms to tree foliage. Also the deposition of different elements was analysed, and compared with that in other parts of Poland.

## 2. METHODS AND STUDY AREA

The study was carried out at Dziekanów Leśny near Warsaw (52°21'N and 20°51'E, at 80 m a.s.l.) in eastern part of the buffer zone of the Kampinos National Park. The study plot was located on the open area (meadow) adjoining the Institute of Ecology – about 150 m from the forest and 50 m from the village road. The Warsaw-Gdańsk highway passed close to the plot (around 500 m), which could be the source of a high input of heavy metals.

Rain collectors were run during the growing seasons (between April and October) in 1997–1999.

According to the recent knowledge, exact measurements of the atmospheric input of elements to ecosystems consider also additional aerosol-gaseous input. Standard bulk precipitation collectors do not measure this additional input with the result that the total element input can be largely underestimated. For this reason I used modified rain collectors with, so called, artificial leaves located above the standard collectors (Stachurski and Zimka 2000). It makes possible the measurement of the aerosol-gaseous input. The following types of collectors were used: 0 (without collecting surfaces), 2, 6, and 12 m<sup>2</sup> m<sup>-2</sup> (Fig. 1) (LAI – leaf area index, here projected area of artificial leaves, calculated as leaf surface per surface area of the funnel inlet). Such a range of LAI corresponds with the most often reported LAI of natural forest stands (Sato 1970, Kram 1998, Cutini *et al.* 1998), and permits the estimation of direct dependence between leaf area and atmospheric input of elements. All parts of the rain collectors were made of polyethylene or polypropylene.

Three water collectors of each type were placed in the plot. Water and filters with dust were collected once over three weeks, and collectors were replaced with clean ones. Measurements of water amount were made

on the plot. As samples were taken from each collector separately, it was possible to sum seasonal inputs and to use statistical analyses. This method was described in detail by Zimka and Stachurski (1996).

Concentrations of cations (Na<sup>+</sup>, N-NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>) and anions (Cl<sup>-</sup>, N-NO<sub>3</sub><sup>-</sup>, S-SO<sub>4</sub><sup>2-</sup>) were determined in two separate analytical series by the ion chromatography (Methrom IC System 690, Switzerland). Concentrations of heavy metals (Zn, Cd, Pb, Cu) were measured by the inverse voltamperometry (DPASV) with the use of a compact polarographic/voltamperometric apparatus (Methrom 646 VA Processor, 675 VA Sample Changer, Switzerland). Phosphate was measured spectrophotometrically (Shimadzu UV-160A, Japan) using the molybdate blue method. Rainwater pH was measured potentiometrically (Orion Analyser 940, USA).

Element concentrations measured in the rainwater were sums of elements contained in bulk precipitation, easily soluble forms of elements contained in dry deposition washed off by rainwater, and elements contained in aerosols and gases intercepted by the artificial leaves.

The total amount of dust particles was calculated as a sum of dust deposition to the filters in consecutive sampling periods and the deposition firmly attached to the foliage surrogate. The latter was measured at the end of each season.

All values were calculated for each date, summed over the season, and recalculated as mean monthly inputs of each element.

## 3. RESULTS

In standard rain collectors (without artificial leaves) the greatest input was found for calcium (in each season from 1014 to 1829 g ha<sup>-1</sup> month<sup>-1</sup>), and sulphur (673–829 g ha<sup>-1</sup> month<sup>-1</sup>). Moderate inputs were observed for chlorine, potassium, ammonium, and nitrate (hundreds of g ha<sup>-1</sup> month<sup>-1</sup> each). The loads of sodium, magnesium, and phosphorus were smaller (less than 200 g ha<sup>-1</sup> month<sup>-1</sup>), and the inputs of hydrogen and heavy metals were the lowest (from 0.04 for cadmium to 64 g ha<sup>-1</sup> month<sup>-1</sup> for zinc) (Tables 1, 2).

The atmospheric input of the majority of elements was much higher in the collectors with large surface of artificial leaves than in the collectors without leaves. A significant





Fig. 1. Rain collectors without (top left phot.) and with artificial leaves 2 (top right phot.), 6 (bottom left phot.), and 12 (bottom right phot.)  $\text{m}^2 \text{m}^{-2}$  LAI (artificial leaf area).



Table 1. Values of  $Q_{10}$  index for LAI (artificial leaf area) and coefficients of linear regression for the relationship between LAI and element loads to rain collectors. Calculations made for the growing seasons of 1997–1999.  $n=36$  (only dust  $n=24$ ). NS – not significant ( $p>0.05$ )

Element	Intercept (a)	Slope (b)	$\pm$ SE	$r^2$	p	$Q_{10}$
Water ( $\text{mm month}^{-1}$ )	66	0.136	0.386	0.004	NS	1
Dust ( $\text{kg ha}^{-1} \text{ month}^{-1}$ )	6.28	0.763	0.113	0.674	<0.0001	2.21
$\text{H}^+$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	4.01	-0.199	0.077	0.164	<0.05	0.50
$\text{Na}^+$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	173	11.74	2.55	0.383	<0.0001	1.68
$\text{N-NH}_4^+$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	310	17.11	3.04	0.483	<0.0001	1.55
$\text{K}^+$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	336	20.97	5.64	0.289	<0.001	1.62
$\text{Mg}^{2+}$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	100	10.54	1.35	0.642	<0.0001	2.05
$\text{Ca}^{2+}$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	1347	109.0	13.1	0.671	<0.0001	1.81
$\text{Cl}^-$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	354	43.1	5.4	0.651	<0.0001	2.22
$\text{N-NO}_3^-$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	298	37.6	4.9	0.633	<0.0001	2.26
$\text{S-SO}_4^{2-}$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	684	52.6	5.5	0.726	<0.0001	1.77
$\text{P-PO}_4^{3-}$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	52	5.4	1.9	0.188	<0.01	2.04
mineral N ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	609	54.7	7.0	0.645	<0.0001	1.90
anions ( $\text{geq ha}^{-1} \text{ month}^{-1}$ )	74	7.2	0.8	0.712	<0.0001	1.97
cations ( $\text{geq ha}^{-1} \text{ month}^{-1}$ )	114	8.6	1.0	0.669	<0.0001	1.75
$\text{Zn}^{2+}$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	56	0.049	0.636	0.000	NS	1
$\text{Cd}^{2+}$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	0.07	0.0040	0.0013	0.226	<0.01	1.57
$\text{Pb}^{2+}$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	0.62	-0.0119	0.0120	0.029	NS	1
$\text{Cu}^{2+}$ ( $\text{g ha}^{-1} \text{ month}^{-1}$ )	3.8	0.125	0.037	0.249	<0.01	1.33

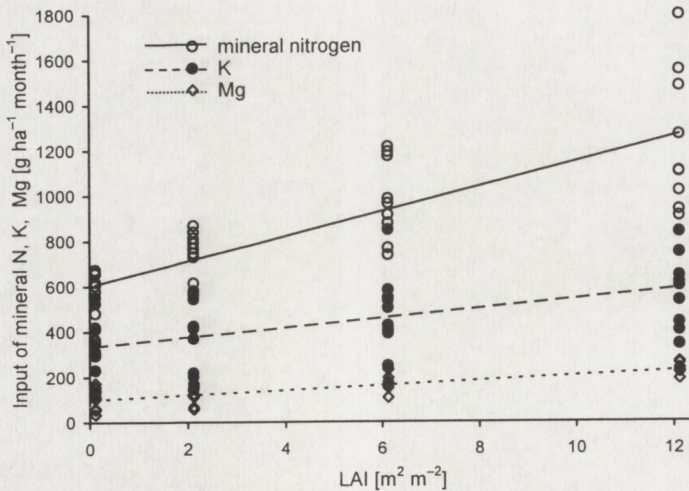


Fig. 2. Relationship between artificial leaf area (LAI) and inputs of mineral nitrogen ( $\text{N-NH}_4 + \text{N-NO}_3$ ), potassium, and magnesium to rain collectors (each season average monthly).  $n=36$ .

increase in the input with increasing area of artificial leaves was observed for all the cations ( $\text{Na}^+$ ,  $\text{N-NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ) and anions ( $\text{Cl}^-$ ,  $\text{N-NO}_3^-$ ,  $\text{S-SO}_4^{2-}$ ). This tendency has also been found for dust and to a lesser degree for cadmium and copper (Table 1). This is

shown in Fig. 2 for total mineral nitrogen (sum of nitrate and ammonium), potassium, and magnesium.

Exceptions to this rule were hydrogen, zinc, lead, and also bulk precipitation. Hydrogen ions showed even a weak negative ten-



Table 2. Values of  $Q_{10}$  index for LAI (artificial leaf area) and coefficients of linear regression for the relationship between LAI and element loads to rain collectors in the growing seasons of 1997–1999.  $n=12$ . NS – not significant ( $p>0.05$ )

## A. Cations and anions

Element	Year	Intercept (a)	Slope (b)	$\pm$ SE	$r^2$	p	$Q_{10}$
$H^+$ (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	7.33	-0.427	0.095	0.668	<0.01	<b>0.42</b>
	1998	1.74	-0.075	0.046	0.205	NS	1
	1999	2.97	-0.097	0.070	0.159	NS	1
$Na^+$ (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	196	18.73	3.12	0.783	<0.0001	<b>1.96</b>
	1998	127	8.10	1.25	0.808	<0.0001	<b>1.64</b>
	1999	195	8.39	3.44	0.373	<0.05	<b>1.43</b>
$N-NH_4^+$ (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	283	24.77	3.32	0.848	<0.0001	<b>1.88</b>
	1998	269	15.98	5.21	0.485	<0.05	<b>1.59</b>
	1999	379	10.56	5.32	0.283	NS	1
$K^+$ (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	186	21.57	6.99	0.488	<0.05	<b>2.16</b>
	1998	341	20.40	3.53	0.770	<0.001	<b>1.60</b>
	1999	482	20.95	7.71	0.425	<0.05	<b>1.43</b>
$Mg^{2+}$ (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	45	14.93	1.09	0.949	<0.0001	<b>4.32</b>
	1998	104	8.48	0.58	0.955	<0.0001	<b>1.82</b>
	1999	152	8.21	1.10	0.849	<0.0001	<b>1.54</b>
$Ca^{2+}$ (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	1014	166.8	7.1	0.982	<0.0001	<b>2.64</b>
	1998	1198	86.9	6.6	0.945	<0.0001	<b>1.73</b>
	1999	1829	73.2	19.3	0.589	<0.01	<b>1.40</b>
$Cl^-$ (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	355	62.1	4.7	0.946	<0.0001	<b>2.75</b>
	1998	290	26.1	3.2	0.871	<0.0001	<b>1.90</b>
	1999	417	41.1	6.2	0.814	<0.0001	<b>1.99</b>
$N-NO_3^-$ (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	315	59.9	3.8	0.962	<0.0001	<b>2.90</b>
	1998	237	28.6	2.4	0.936	<0.0001	<b>2.21</b>
	1999	343	24.2	3.9	0.794	<0.0001	<b>1.71</b>
$S-SO_4^{2-}$ (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	673	66.8	3.3	0.976	<0.0001	<b>1.99</b>
	1998	551	44.6	3.5	0.943	<0.0001	<b>1.81</b>
	1999	829	46.4	6.3	0.845	<0.0001	<b>1.56</b>
$P-PO_4^{3-}$ (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	31	2.6	1.1	0.348	<0.05	<b>1.84</b>
	1998	42	5.1	2.0	0.400	<0.05	<b>2.21</b>
	1999	84	8.5	3.7	0.348	<0.05	<b>2.01</b>
mineral N ( $N-NH_4^+$ + $N-NO_3^-$ ) (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	598	84.6	6.3	0.947	<0.0001	<b>2.41</b>
	1998	506	44.6	5.9	0.849	<0.0001	<b>1.88</b>
	1999	723	34.8	8.6	0.622	<0.01	<b>1.48</b>
anions (geq ha <sup>-1</sup> month <sup>-1</sup> )	1997	74	10.2	0.6	0.971	<0.0001	<b>2.38</b>
	1998	59	5.6	0.4	0.943	<0.0001	<b>1.95</b>
	1999	88	5.8	0.7	0.862	<0.0001	<b>1.66</b>
cations (geq ha <sup>-1</sup> month <sup>-1</sup> )	1997	88	12.7	0.8	0.961	<0.0001	<b>2.44</b>
	1998	102	7.1	0.5	0.951	<0.0001	<b>1.70</b>
	1999	152	6.0	1.6	0.589	<0.01	<b>1.39</b>



## B. Water, dust, and trace metals

Element	Year	Intercept (a)	Slope (b)	$\pm$ SE	$r^2$	p	$Q_{10}$
Water (mm month <sup>-1</sup> )	1997	74	0.409	0.296	0.160	NS	1
	1998	52	0.484	0.365	0.150	NS	1
	1999	71	-0.484	0.346	0.164	NS	1
Dust (kg ha <sup>-1</sup> month <sup>-1</sup> )	1997	5.28	0.638	0.071	0.890	<0.0001	<b>2.21</b>
	1998	7.29	0.889	0.151	0.776	<0.001	<b>2.22</b>
Zn <sup>2+</sup> (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	43	0.087	0.595	0.002	NS	1
	1998	64	0.032	0.784	0.000	NS	1
	1999	61	0.028	1.385	0.000	NS	1
Cd <sup>2+</sup> (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	0.09	0.0034	0.0016	0.319	NS	1
	1998	0.04	0.0073	0.0021	0.549	<0.01	<b>2.83</b>
	1999	0.07	0.0012	0.0019	0.035	NS	1
Pb <sup>2+</sup> (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	1.12	-0.0343	0.0138	0.383	<0.05	<b>0.69</b>
	1998	0.32	0.0034	0.0051	0.041	NS	1
	1999	0.42	-0.0049	0.0097	0.025	NS	1
Cu <sup>2+</sup> (g ha <sup>-1</sup> month <sup>-1</sup> )	1997	4.5	0.029	0.047	0.038	NS	1
	1998	3.2	0.163	0.025	0.806	<0.001	<b>1.51</b>
	1999	3.9	0.182	0.092	0.282	NS	1

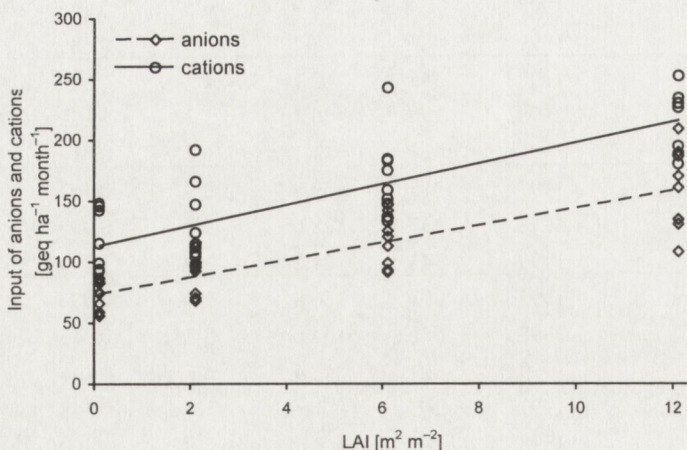


Fig. 3. Atmospheric input (each season average monthly) of anions and cations (sums of equivalent ionic values of individual elements) in relation to artificial leaf area (LAI).

dency ( $r^2=0.16$ ,  $p<0.05$ ,  $n=36$ ), that is, a decrease in input with increasing artificial leaf area.

To compare the inputs in the gradient of LAI for different elements, a  $Q_{10}$  index was calculated, which shows how many times the input of an ion will be higher when LAI increases from 0 to 10  $m^2 m^{-2}$ . For the majority of ions,  $Q_{10}$  was close to 2, that is, the deposition of ions to collectors with the collecting

area of 10  $m^2 m^{-2}$  was twice as high as that to a standard rain collector. The values of this index were highest for nitrate ions – 2.26 and chlorine ions – 2.22. Also dust reached a high value of  $Q_{10} = 2.21$ . The lowest values of  $Q_{10}$  were recorded for ammonium – 1.55, potassium – 1.62, sodium – 1.68, and for heavy metals, such as copper – 1.33, and cadmium – 1.57 (for zinc and lead the increase was not significant) (Table 1).



The same analysis was performed for anions and cations. Their inputs were calculated as equivalent ionic values. It has been found that both of them increased significantly in leaf area gradient, and reached  $Q_{10}$  of 1.97 for anions and 1.75 for cations (Fig. 3). Such a high increase in the input of cations, mainly alkaline ions, probably explains the absence of positive correlation between leaf area and hydrogen input.

Despite large year-to-year differences in the load of elements, they had no effect on the increase in element input with artificial leaf area. This relationship followed a similar pattern in all three seasons, and almost in all cases larger loads of elements were coupled with larger artificial leaf area (Table 2), as exemplified by sulphate sulphur (Fig. 4).

An increase in element input with artificial leaf area was also observed when bulk precipitation did not vary. In all kinds of rain collectors, water influx was similar (Fig. 5).

(Table 2). Differences in the load between years were mainly dependent on the element. As a result, ratios between elements varied with time. For example, in 1997 the input of nitrate was much higher than the input of potassium, but in 1999 the load of potassium was higher than that of nitrate (Table 2).

In the case of the hydrogen ion, between year differences were especially important. In 1997, hydrogen input was the highest,  $7.33 \text{ g ha}^{-1} \text{ month}^{-1}$ , and it significantly decreased with increasing area of artificial leaves ( $Q_{10}=0.42$ ,  $r^2=0.67$ ,  $p<0.01$ ,  $n=12$ ). On the contrary, in the next two seasons, when the atmospheric input was much smaller ( $1.74$  and  $2.97 \text{ g ha}^{-1} \text{ month}^{-1}$ ), the decreasing tendency was statistically insignificant (Fig. 6).

In similar studies conducted in the Karkonosze Mts. (south-western Poland) disproportions were found among elements, resulting from differences in their input with increasing leaf area (Stachurski and

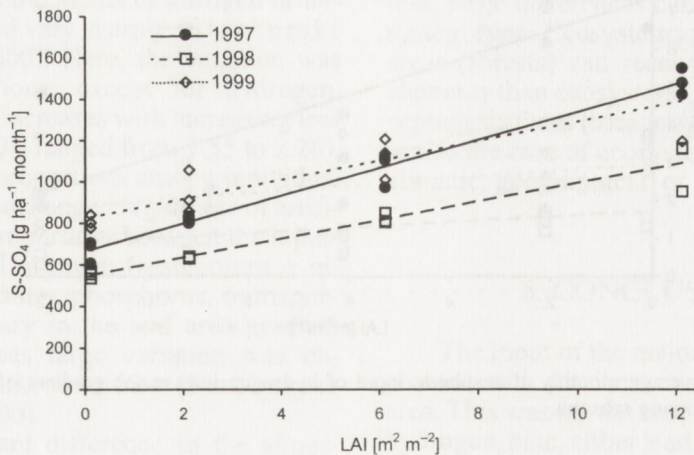


Fig. 4. Monthly average atmospheric input of sulphate sulphur in the gradient of artificial leaf area (LAI) during three growing seasons.

This implies that the increase in the input of elements with artificial leaf area was mostly determined by their concentrations. This increase was due to the interception of gases and aerosols by artificial leaf area, which was independent of water input.

The importance of ion concentrations in water, rather than of water influx itself, can also be inferred from differences in inputs between years. Although the water influx was highest in 1997, the input of most ions was lowest, whereas it was the highest in 1999

Zimka 2000). It was interesting to know whether this was also the case near the Kampinos Forest in less polluted central Poland. It appeared that, unlike in the Karkonosze Mts., proportions among elements generally did not vary with the increasing artificial leaf area. For example, the ratio of mineral nitrogen (ammonium + nitrate) to phosphorus, magnesium, or potassium was fairly unchanged regardless of artificial leaf area (Fig. 7).



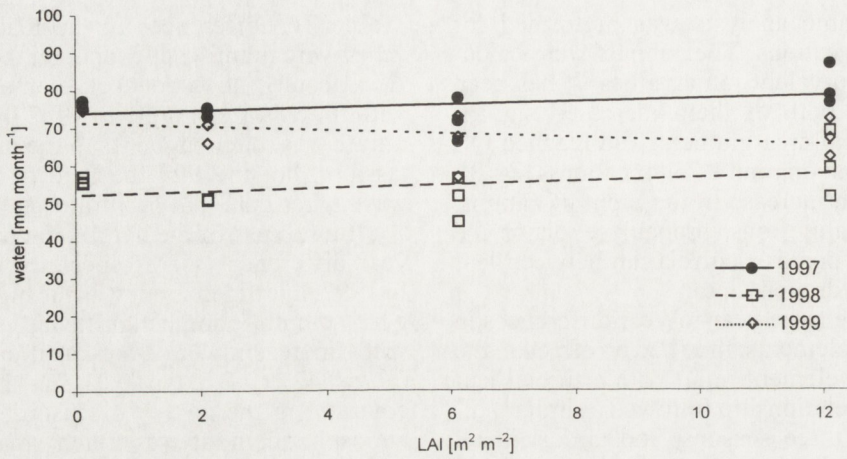


Fig. 5. Atmospheric input of bulk precipitation in the gradient of artificial leaf area (LAI); average monthly during three growing seasons.

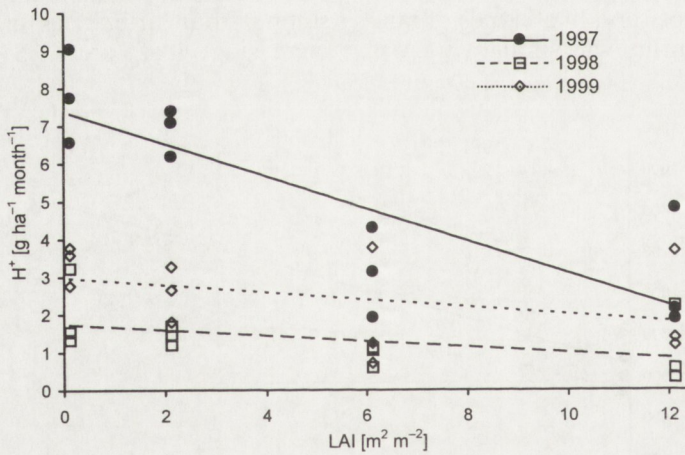


Fig. 6. Each season average monthly atmospheric input of hydrogen ions in the gradient of artificial leaf area (LAI) during three growing seasons.

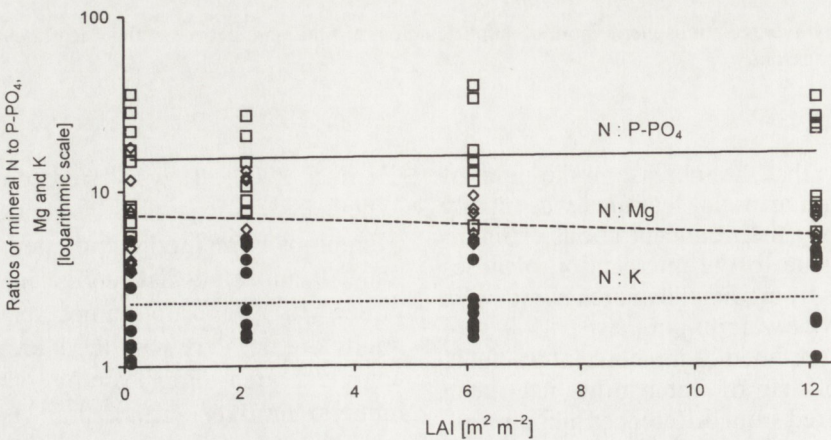


Fig. 7. Ratios of the input of mineral nitrogen to phosphorus, magnesium, and potassium in the gradient of artificial leaf area (LAI). Logarithmic scale.



#### 4. DISCUSSION

In Poland, studies of element input to ecosystems were carried out several times (Zimka 1989, Tarabuła 1995, Grodzińska and Laskowski 1996, Zimka and Stachurski 1996, Szarek-Łukaszewska 1999), and in the Karkonosze Mts. also the interception of ions by leaf surface was analysed (Stachurski and Zimka 2000). Recent studies confirm the importance of leaf surface for dry deposition of elements. The linear increase in element load with increasing artificial foliage area also confirms that it is especially important in forest ecosystems, where foliage area is very large, so differences between the atmospheric input of elements and their total input are the largest.

Changes in proportions among ions caused by variation in their inputs with increasing artificial leaf area were estimated in the Karkonosze Mts. For example, the inputs of potassium or phosphorus ions did not increase, whereas the inputs of nitrogen or hydrogen increased very sharply (Stachurski and Zimka 2000). Here, the situation was different. All ions, except for hydrogen, showed similar increases with increasing leaf area gradient ( $Q_{10}$  ranged from 1.55 to 2.26). Consequently, proportions among individual ions remained unchanged regardless of artificial leaf area. Proportions between the inputs of total mineral nitrogen (ammonium + nitrate) and potassium, phosphorus, or magnesium did not vary in the leaf area gradient (Fig. 7), whereas large variation was observed in the Karkonosze Mts. (Stachurski and Zimka 2000).

An important difference in the atmospheric input between the Kampinos Forest and Karkonosze Mts. is the flux of hydrogen ions. Whereas in the Karkonosze, acidity increased with artificial leaf area, this was not the case in the Kampinos Forest, where  $H^+$  load was maintained at constant level or even decreased. This difference was a result of the more proportional increase in the input of other elements to the Kampinos Forest, especially of stable proportions between anions and cations buffering them. In the Karkonosze Mts. the increase in anions was much larger than in cations (Stachurski and Zimka 2000).

Differences in the atmospheric input of elements could be related to concentrations of air pollution. The region of Karkonosze Mts. is affected by heavy loads of S and N

from the atmosphere (Juda-Rezler and Abert 1994) – so called “Black Triangle”.

Also climatic differences between the study areas could affected the atmospheric inputs. Frequent fog, large quantities of cloud droplets, or dew condensed on different surfaces, including artificial foliage, lead to increased water input, as observed in the Karkonosze Mts. (Stachurski and Zimka 2000), and this could be a reason for the increase in element input with leaf area. But no such relationship was observed in the present study. This implies that increases in element input are independent of climatic differences, and they depend on the deposition of gaseous or aerosol forms of ions to all kinds of surfaces, rather than on the increasing rainwater input.

Differences in dry deposition of elements were reported between different regions of the world (Lovett and Kinsman 1990), climates (Bajić and Đuričić 1995), or altitudes (Lindberg *et al.* 1990). Nevertheless, large differences can be related to ecosystem type. Ecosystems with larger foliage areas (forests) can receive a larger pool of elements than ecosystems with smaller intercepting surfaces (meadows, open areas). This is also the case of ecosystems under the same climatic, geographical, or other conditions.

#### 5. CONCLUSIONS

The input of the majority of elements increased with the increasing gradient of leaf area. This was not the case only for the ions of hydrogen, zinc, either lead. In terms of  $Q_{10}$  index, that is, when leaf area increased from 0 to  $10 \text{ m}^2 \text{ m}^{-2}$ , the input of elements typically ranged from 1.55 ( $N-NH_4^+$ ) to 2.26 ( $N-NO_3^-$ ). A little lower values of  $Q_{10}$  were observed for heavy metals.

The increase in element input with increasing artificial leaf area was a result of increasing concentrations of ions in water, as bulk precipitation was almost the same regardless of the leaf area.

The inputs of different elements increased proportionally to the artificial leaf area, thus proportions among the elements did not depend on leaf area.

No positive correlation was found between  $H^+$  input and leaf area, so that acidity did not increase. It was due to a balanced increase in the input of cations and anions.



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## 6. SUMMARY

The purpose of the study was to estimate tile atmospheric input of elements to ecosystems of the Kampinos National Park, and to evaluate the contribution of the aerosol-gaseous fraction to this input. A method of so-called "artificial trees" was used. Traps with catching areas of 0, 2, 6, and 12 square metres per square metre were applied (Fig. 1). The study was conducted in the growing seasons (April-October) of 1997–1999.

It has been found that the input of  $\text{Ca}^{2+}$  was highest (mean  $1347 \text{ g ha}^{-1} \text{ month}^{-1}$ ), followed by  $\text{S-SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{N-NH}_4^+$ ,  $\text{N-NO}_3^-$ ,  $\text{Na}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{P-PO}_4^{3-}$ ,  $\text{Zn}^{2+}$ ,  $\text{H}^+$ ,  $\text{Cu}^{2+}$ ,  $\text{Pb}^{2+}$ , and the input of Cd was lowest (mean  $0.07 \text{ g ha}^{-1} \text{ month}^{-1}$ ) (Table 1). The input of the great majority of elements clearly increased with surface area of the artificial foliage ( $\text{Na}^+$ ,  $\text{N-NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{N-NO}_3^-$ ,  $\text{S-SO}_4^{2-}$ ,  $\text{P-PO}_4^{3-}$ ). The increase was less pronounced for  $\text{Cd}^{2+}$  and  $\text{Cu}^{2+}$  (Tabs 1 and 2, Fig. 2). In general, with surface area increasing from 0 to  $10 \text{ m}^2 \text{ m}^{-2}$  ( $Q_{10}$  index), increases in the input of elements varied from 1.55 ( $\text{N-NH}_4$ ) to 2.26 ( $\text{N-NO}_3$ ). This process was not observed only for  $\text{Zn}^{2+}$ ,  $\text{Pb}^{2+}$ , atmospheric water (Fig. 5), and  $\text{H}^+$  for which even a weak opposite tendency was noted as its load decreased with increasing trapping surface (Fig. 6).

Increasing surface of the artificial foliage was accompanied by proportional increases in the loads of both anions and cations that neutralised them. Consequently, the acidity of rainfall did not vary (Fig. 3).

These tendencies occurred in all the three years, and differences in the results were small (Table 2, Fig. 4).

As a result of parallel increases in the loads of most elements with increasing foliage surface, proportions among elements were maintained at a relatively stable level in the gradient of the foliage surface (Fig. 7).

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