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Małgorzata KWIECIEŃ

Department of Plant Ecology, Institute of Ecology,
Polish Academy of Sciences,
Dziekanów Leśny near Warsaw, 05-092 Łomianki

AEROSOL INTERCEPTION BY FOREST CANOPY IN A HIGHLY INDUSTRIALIZED REGION*

ABSTRACT: This is a new method of estimating aerosol interception by forest canopy. The aerosols trapped by the canopy of a pine-oak forest (Pino-Quercetum association) averaged 199.22 $kg \cdot ha^{-1}$, vegetation $season^{-1}$ which was equal to 40.52% of all inorganic dust fall on the forest floor. The aerosols were an additional source of elements, e.g. of nitrogen – 15.07 $kg \cdot ha^{-1} \cdot$ vegetation $season^{-1}$. At the same time the mean input of nitrogen from the atmosphere was 15.26 $kg \cdot ha^{-1} \cdot$ vegetation $season^{-1}$ in the heavier dust fraction and in rain.

KEY WORDS: Aerosols, filtering, forest ecosystem, dust fall, nitrogen input, deposition, canopy, industrial region.

1. INTRODUCTION

The input of the elements from the atmosphere is the main problem in studies on their cycling. Its proper determination is the condition of correct calculation of nutrient budget. Proper estimation of the total amount of elements entering from the atmosphere to the ecosystem should take into consideration, if possible, the following ways of input: as gas, in rain water, dusts and aerosols. The input with rain and dust is relatively well know, whereas in the last years there is an increased interest in the little known aerosol and gas inflow.

Some papers dealing with the access of elements in rain water mention the additional, aerosol input (C a r l i s l e et al. 1966, E r i k s s o n 1966, W h i t e 1969, N i h l g ä r d 1970).

Although the interest in this kind of nutrient input is increasing and frequently metioned in papers it is not estimated quantitatively in real ecosystems because of

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methodical difficulties (Nihlgärd 1970, White and Turner 1970, Swank and Henderson 1976, Henderson et al. 1977, Lindberg and Harriss 1981, Kwiecień 1986).

Studies on the settlement of small particles on the vegetation are mainly based on laboratory and field experiments with artificially produced aerosols (Chamberlain and Chadwick 1966, Schinn 1978, Sehmel 1980, Gmur et al. 1983a, 1983b). They indicate a great variability of settlement of small particles in relation to surface area and existing conditions (Chamberlain 1967, White and Turner 1970, Aylor and Parlange 1975, Wedding et al. 1975).

White and Turner (1970) in their work on the inflow rate of elements in aerosols have tried to combine experimental studies with real phemomena in the ecosystem. Settlement coefficients of aerosols on plants and filters obtained in experiments with artificially produced aerosols were used for empirical data in spite of the authors' doubts.

The publication of Mayer and Ulrich (1974) is an example of using indirect methods for estimating the input of nutrients together in aerosols and gases. The studies have been limited to soluble compounds leached from fine dust depositing on tree crowns and gases dissolving in rain. Theoretical calculations of aerosol input of elements are based on data on the enrichment of rain water while passing through canopies of coniferous and deciduous trees in winter.

Wiman and Agren (1985), Wiman et al. (1985) and Wiman and Lanneforsa (1985) present direct method of investigating the trapping of aerosols by forest ecosystem. The mathematical model based on fifty parameters simultaneously measured in the area shows the complec character of this phenomenon and various factors affecting it. However, specific data on the number of aerosols stopped by the ecosystem were not published.

In highly industrialized areas the nutrients input in the aerosol form seem to be especially significant. On areas, where the dustiness of air is especially high the trapped aerosols may be an additional source of supplying ecosystems in elements. Neglecting this input may produce errors in calculating the nutrient budget and incorrect interpretation of natural processes.

The aim here has been a presentation of a relatively simple, field method of quantitative estimation of trapping inorganic dust of aerosol type by the canopy in the forest ecosystem.

2. METHODICAL ASSUMPTIONS

The aim here has been an empirical determination of the amount of inorganic aerosols trapped by the canopy and being an additional source of elements for the ecosystem. Determination of this parameter allows to find the real amount of inorganic dusts – the heavier fraction gravitating down and the aerosol one flowing in the air – reaching the forest floor during the vegetation season.

Dusts and aerosols coming from atmosphere to the forest ecosystem partly settle in tree crowns and partly fall to the forest floor. When the aerosols are not trapped the total inorganic dust settled and falling under the canopy equals the gravitational dust fall from atmosphere, i.e.:

$$C_1 + L_1 = D \tag{1}$$

where C_1 is the inorganic dust fall on forest floor, L_1 – amount of inorganic dust settled in tree crowns, D – gravitational fall of inorganic dust.

But if aerosols will be trapped in the zone of the canopy the total deposition in crown and inorganic dust fall under tree crowns will have higher values than the gravitational dust fall. The difference between these values is a measure of aerosol trapping. This is described by the following equation:

$$A = (C_2 + L_2) - D \tag{2}$$

where A is the amount of aerosols trapped by the canopy, C_2 – total fall of aerosols and of heavier fraction of inorganic dust, L_2 – total deposition of aerosols and of the heavier fraction of inorganic dust in the canopy, D – gravitational fall of the heavier fraction of inorganic dust.

Although an empirical determination of dust fall under the canopy is not difficult from the methodical point of view, still there is a kind of inconvenience. The particles falling on forest floor are not only of inorganic but also of organic origin – flower pollen, faeces of phytophages etc. This means that the dust falling under the canopy is a mixture of these two components. Thus in order to determine the fall of both fractions of inorganic dusts from tree crowns, the fall of particles of organic origin should be subtracted from the fall of mixed dust on forest floor.

Thus, the equation for the quantity of aerosols trapped by the zone of the canopy takes the form of:

$$A = \{(M - O) + L_2\} - D \tag{3}$$

where symbols A, L_2 and D are the same as before, whereas M – mixed dust fall on forest floor and O – organic dust fall under tree crowns. All data in this equation can be determined empirically, except the organic dust fall.

This parameter – indispensable to calculate A – can be determined knowing that industrial dust on the area examined had a relatively low carbon content, 10.63–11.60% on the average per season (K w i e c i e ń 1986). Particles of organic origin usually contain about 40% of this element. Data from experimental investigations on trapping of aerosols (K w i e c i e ń 1986) show that carbon concentrations in inorganic dust falling gravitationally and in aerosols do not differ. Thus, the carbon content in gravitationally falling dust is assumed as characteristic for all inorganic dusts reaching the forest floor. Having empirical data on the amount of mixed dust fall under the canopy and carbon concentration in organic, inorganic and mixed dusts the following equation can be presented:

$$\begin{cases} M = O + C_2 \\ aM = bO + cC_2 \end{cases} \tag{4}$$

where symbols M, O and C_2 are used in the same meaning as before, whereas a stands for the per cent of carbon in mixed dust, b – carbon per cent in organic dust, c – carbon per cent in inorganic dust.

This set of equations allows to calculate the amount of organic dust in mixed dust that falls on forest floor:

$$O = \frac{M(a-c)}{(b-c)} \tag{5}$$

Now the amount of inorganic aerosols trapped by the canopy can be estimated as other parameters in equation 3 are relatively easy to be measured directly under field conditions.

3. AREA, MATERIAL AND METHODS

Studies on the trapping of inorganic aerosols by the canopy were conducted in a mixed Pino-Quercetum forest. The pine *Pinus sylvestris* L. dominated in the tree layer, whereas *Quercus robus* L., *Q. sessilis* Ehrh. and *Betula verrucosa* Ehrh. and *B. pubescens* Ehrh. – in the undergrowth. *Pteridium aquilinum* L. dominated in the herb layer. The object of investigations was the place called Kamień, 5 km north-east from Rybnik, Upper Silesia.

Samples were taken during the vegetation seasons 1981 – 1983, between April and November.

Consistently with equations (3) and (5) (chapter 2) A could be calculated knowing the following parameters: (1) gravitational fall of heavier fraction of inorganic dust (D), (2) mixed dust fall under tree crowns (M), (3) organic dust fall under tree crowns (O), (4) carbon concentration in mixed dust (a), (5) carbon concentration in organic dust (b), (6) carbon concentration in inorganic dust (c).

Data on the gravitational fall of inorganic dust (D) were obtained placing at random fourteen dust and rain water traps on an unforrested area close to the ecosystem examined. Filters used in this type of traps guarantee that all particles of a diameter bigger than 1.0 μm are stopped. The structure and functioning of the trap, including its usefulness in determining the amount and chemical composition of dust, are described by Stachurski and Zimka (1982) and Kwiecień (1986).

Mixed dust fall (M) on forest floor was estimated using the same type of traps. Twenty-four traps were distributed at random under tree crowns, deep in the forest.

The method of taking monthly dust samples from traps, as well as ways of determining the amount of fine particles fall and preparing the material for chemical analyses are given by Kwiecień (1986).

Organic dust (O), otherwise than other parameters, could not be estimated directly. It was calculated indirectly on the basis of equation (5) (chapter 2). Apart from data on mixed dust fall (M), it was indispensable to determine carbon concentration in mixed (a), organic (b) and inorganic dust (c).

Samples of organic dust for chemical analyses were obtained during rainless periods by means of daily mixed dust fall under the canopy. The organic particles were picked under an eyepiece – mainly the faeces of phytophages.

In thus sampled organic, inorganic and mixed dust the carbon content was determined. Atomic analyser Carlo Erba was used for making analyses – for a detailed description see K w i e c i e ń (1986).

Dusts and aerosols in the canopy deposit on leaves, branches and trunks. As the leaves cover a greater surface area than branches and trunks taken together, the studies have been limited to the former, considering the latter as of little significance. Also, it was taken into consideration that the time of dust depositing on leaves usually does not exceed one vegetation season, at the end of which the leaves together with dust fall on the forest floor, whereas the deposition of dust on trunks and branches may last many years.

In order to determine the amount of inorganic dust on leaves, dominant tree species leaves falling were taken at random at the end of the vegetation season (October). For oak and birch 30 leaves were taken. Pine needles: one-, two-, and three-years old were taken of branches shot at random, 50 needles from each age group.

The amount of inorganic dust was investigated on needles one-, two- and three-years old, four-years old needles were practically not found on branches. The amount of deposited dust increased successively by 1/3 of the final value recorded on three-years old needles. Thus, it was assumed that the amount of dust deposited on three-years old needles approximated annual deposition on al three age groups of needles. Therefore, only data on dust and aerosol deposition on three-years old needles were used.

Samples of falling needles and leaves were dried for 24 hrs at 65°C and then weighed with an accuracy to 0.01 mg. Each leaf was weighed separately, whereas 50 needles forming one sample were weighed together. The dust was removed by a sponge with distilled water. Clean needles and leaves were dried again and weighed analogously. The difference in weight was the measure of inorganic dust settlement on a leaf during the vegetation season.

In order to determine the amount of leaf fall of each dominant species, once a month 24 random samples of dead organic matter fall were taken – from plots identical in size and cleaned off litter. Out of these samples needles and leaves were picked out and divided into species. Leaves of non-dominant tree species were put together as mixed samples. All samples were dried for 24 hrs at 65°C and weighed with an accuracy to 0.01 mg.

Information on the deposition of inorganic dust on leaves during the vegetation season (in $kg \cdot ha^{-1}$) for a specific species was obtained multiplying the amount of dust on leaves (in mg per 1 g of leaf) by seasonal leaf fall (in $kg \cdot ha^{-1}$). The period of dust deposition for pine needles lasts 12 months and not 7 months as in deciduous trees. Therefore, these deposition values for pine were multiplied by coefficient 0.58 (7 : 12) to obtain the quantity of dust deposition on needles during the vegetation season.

Total amount of dust and inorganic aerosols on leaves in the canopy zone during the vegetation season was obtained by summing up the values of this parameter for particular tree species.

Table 1. Dynamics of organic and inorganic dust fall under the canopy of mixed forest (Pino-Quercetum) on the area of the Rybnik Coal Region in the vegetation season of 1983 ($kg \cdot ha^{-1} \cdot veg.\ season^{-1}$)

Period of investigations	Mixed dust fall under the canopy M	Per cent of carbon in mixed dust a	Per cent of carbon in inorganic dust c	Calculated organic dust fall under the canopy O*	Calculated inorganic dust fall under the canopy C_2**
22 March. – 19 Apr.	89.92	14.00	8.14	15.30	74.62
19 Apr. – 24 May	75.36	19.94	10.10	22.84	52.52
24 May – 9 June	67.76	21.01	10.06	22.82	44.94
9 June – 13 July	54.79	16.37	11.91	7.97	46.82
13 July – 17 Aug.	65.34	16.94	15.15	4.26	61.08
17 Aug. – 21 Sept.	70.36	15.98	12.16	8.84	61.52
21 Sept. – 19 Oct.	61.14	18.09	10.92	13.85	47.29

*Parameter calculated from the equation $O = \frac{M(a-c)}{(b-c)}$; b – mean carbon content in organic dust $\bar{x} = 42.57\%$.

**Parameter calculated from the equation $C_2 = M - O$.

4. ESTIMATION OF INORGANIC AEROSOL TRAPPED BY THE CANOPY IN THE FOREST ECOSYSTEM

The methods applied allow to obtain empirical data indispensable for estimating the amount of inorganic aerosols trapped by the canopy by means of an equation:

$$A = \{(M - O) + L_2\} - D$$

Some data necessary to solve this equation were obtained directly from field measurements, such as mixed dust fall under the canopy (M) or gravitational inorganic dust (D). Other values were not calculated yet, such as deposition of inorganic dust on leaves (L_2), or had to be calculated indirectly – organic dust fall on forest floor (O).

The main parameter allowing for precise estimation of the amount of trapped aerosols is organic dust fall under the canopy. It has been determined for monthly periods, using equation (5) (chapter 2). For example, Table 1 shows the calculation of this parameter in the season of 1983. It provides information about the amount of organic and inorganic dust fall on forest floor in successive months. The results allow to

Table 2. Organic and inorganic dust fall under the canopy ($kg \cdot ha^{-1} \cdot$ veg. $season^{-1}$)

Fall	1981	1982	1983
of mixed dust under the canopy (M)	439.04	470.38	485.45
of inorganic dust under the canopy (C_2)	372.53	366.91	395.11
of organic dust under the canopy (O)	66.51	103.47	90.34
Per cent of organic dust in mixed dust	15.15	22.00	18.61

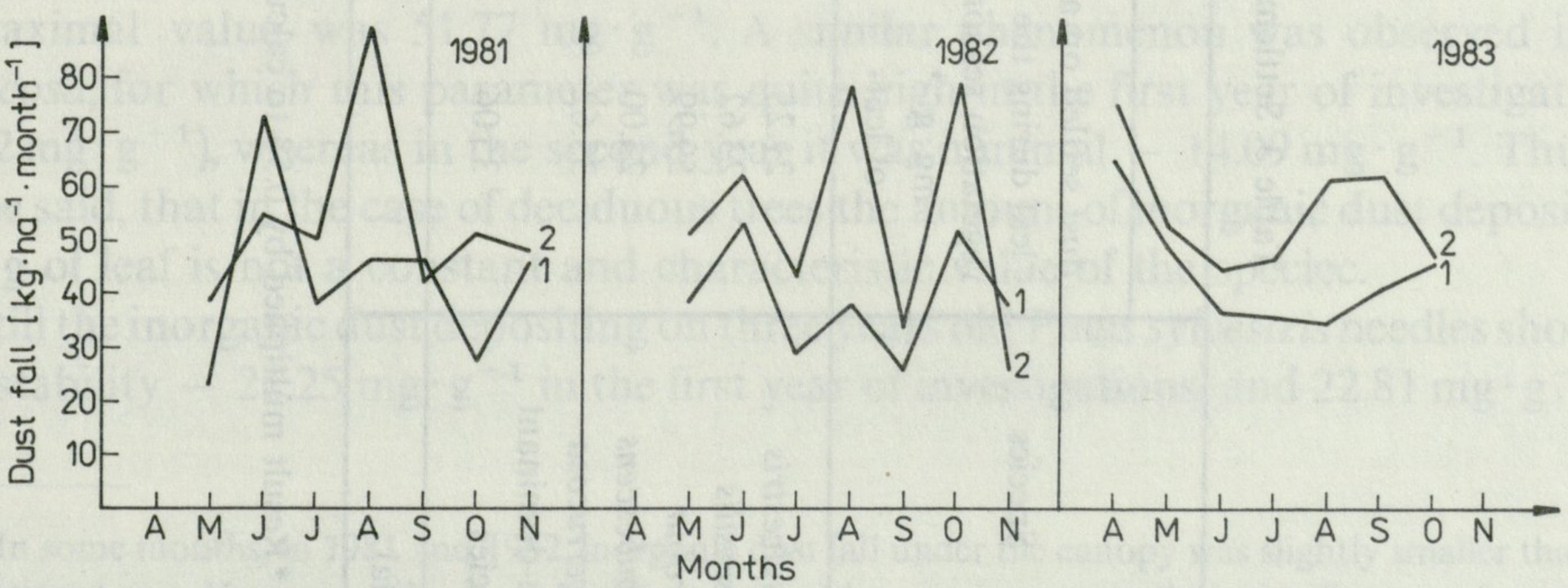

Fig. 1. The gravitational fall rate of inorganic dust from the atmosphere (1) and inorganic dust under the canopy (2) of mixed forest Pino-Quercetum

Table 3. Settlement of inorganic dust on leaves and their fall together with litter on the forest floor

Species	1982			1983		
	dust settled on a leaf during the vegetation season $mg \cdot g^{-1}$ of leaf	leaf fall $kg \cdot ha^{-1} \cdot veg.\ season^{-1}$	dust fall on the forest floor with leaf fall $kg \cdot ha^{-1} \cdot veg.\ season^{-1}$	dust settled on a leaf during the vegetation season $mg \cdot g^{-1}$ of leaf	leaf fall $kg \cdot ha^{-1} \cdot veg.\ season^{-1}$	dust fall on the forest floor with leaf fall $kg \cdot ha^{-1} \cdot veg.\ season^{-1}$
P. sylvestris	21.25	1599.20*	19.71	22.81	2311.91	30.59*
Q. sessilis	23.62	982.74	23.22	51.77	812.64	42.07
Q. robur	59.99	507.17	30.42	31.46	426.03	13.40
B. pubescens	23.00	846.42	19.47	15.44	798.12	12.32
B. verrucosa	33.62	603.98	20.31	14.09	551.82	7.77
non-dominant species	35.06	130.05	4.56	28.19	109.68	3.09
Total		4669.56	117.69		5010.20	109.24

*Result multiplied by 0.58 to calculate the annual settlement into seasonal.

say that over the entire season inorganic dust fall was higher than that of particles of organic origin. Monthly inorganic dust fall under the canopy varied slightly in time, ranging between 46.82 and 74.62 $kg \cdot ha^{-1}$. Whereas organic dust fall had distinct seasonal dynamics with the maximum in spring (22.84 $kg \cdot ha^{-1} \cdot month^{-1}$ at the turn of May). Then the fall of organic particles on forest floor decreased to 4.26 – 13.85 $kg \cdot \cdot ha^{-1} \cdot month^{-1}$.

The organic and inorganic dust fall under the canopy in the seasons of 1981 – 1983 is given in Table 2. Seasonal inorganic dust fall was over three times as much as the amount of particles of organic origin falling on forest floor, and fluctuated between 366.91 and 395.11 $kg \cdot ha^{-1}$. And organic dust fall fluctuated between 66.51 and 103.47 $kg \cdot ha^{-1} \cdot vegetation\ season^{-1}$. Although dust of organic origin was only 15.15 – 22.00% of dust mixture falling under the canopy, its fall was quite considerable – on the average 86.77 $kg \cdot ha^{-1} \cdot veg.\ season^{-1}$. Omitting the fall of organic particles in calculations would increase at the same time the amount of inorganic dust falling on forest floor, overestimating thus the trapping role of the canopy zone.

The rate of gravimetric fall of inorganic dust from atmosphere and the inorganic dust fall under the canopy are shown in Figure 1. The dust fall on forest floor is consistently higher than the gravitational dust fall from the atmosphere[1]. Greater inorganic dust fall under tree crowns indicates the phenomenon of aerosol trapping by the canopy. The extent of this phenomenon is shown by the field between curves illustrating the gravitational dust fall from the atmosphere and inorganic dust fall under the canopy. This is quite stable, 57.89 – 114.22 $kg \cdot ha^{-1} \cdot veg.\ season^{-1}$.

This preliminary analysis leaves no doubt that the canopy zone traps aerosols from the atmosphere, some 60 – 110 $kg \cdot ha^{-1} \cdot veg.\ season^{-1}$. The increase of inorganic dust fall under the canopy is not a measure of all aerosols trapped as their settling on leaves should be included. Table 3 presents data on the amount of dust depositing on a leaf and on leaf fall. The amount of dust depositing on leaves of dominant tree species (in mg per 1 g of leaf) was quite diversified. It was between 14.09 $mg \cdot g^{-1}$ (*Betula verrucosa*) and 59.99 $mg \cdot g^{-1}$ (*Quercus robur*). In case of deciduous trees it seems that the amount of dust depositing on a leaf is not a characteristic feature of the species at the values vary for the same species in different seasons. And so, for example, the amount of dust that deposited on a *Quercus sessilis* leaf in 1982 was small (23.62 $mg \cdot g^{-1}$), whereas in 1983 its maximal value was 51.77 $mg \cdot g^{-1}$. A similar phenomenon was observed in *B. verrucosa*, for which this parameter was quite high in the first year of investigations (33.62 $mg \cdot g^{-1}$), whereas in the second year it was minimal – 14.09 $mg \cdot g^{-1}$. Thus, it can be said, that in the case of deciduous trees the amount of inorganic dust depositing on 1 g of leaf is not a constant and characteristic value of the speciec.

Still the inorganic dust depositing on three years old *Pinus sylvestris* needles showed high stability – 21.25 $mg \cdot g^{-1}$ in the first year of investigations, and 22.81 $mg \cdot g^{-1}$ in

[1] In some months, in 1981 and 1982, inorganic dust fall under the canopy was slightly smaller than the gravitational one. However, differences between these values were statistically insignificant and remained within the standard error.

the second year. The recorded values were a result of a process lasting three years, which could decrease considerably the seasonal variability of this parameter.

Despite the quite high seasonal variability of dust depositing on leaves of species being main fall components, and the leaf fall quantity, the amount of inorganic dust reaching the forest floor was similar in successive years (Table 3). Together with leaf fall this was up to 109.24 and 117.69 $kg \cdot ha^{-1} \cdot veg.\ season^{-1}$ of dust and inorganic aerosols. Thus, for the season of 1981, when this parameter was not examined, the mean value from two successive years was taken into consideration.

Table 4. The amount of aerosols trapped by the canopy of mixed forest (Pino-Quercetum) ($kg \cdot ha^{-1} \cdot veg.\ season^{-1}$)

Year	Amount of inorganic dust		Total inorganic dust fall on the forest floor	Dust fall from the atmosphere	Amount of aerosols trapped by the canopy
	settled on leaves L_2	falling under the canopy C_2	$L_2 + C_2$	D^{**}	$A = (L_2 + C_2) - D$
1981	113.46*	372.53	485.99	314.64	171.35
1982	117.69	366.91	484.60	252.69	231.91
1983	109.24	395.11	504.35	309.96	194.39

*Mean value calculated on the basis of seasons 1982 and 1983.

**Data from paper by Kwiecień (1986).

At this moment it has been possible to determine the amount of inorganic aerosols trapped by the canopy in forest ecosystems as all parameters of equation (4) (chapter 2) are known. The results of calculations are presented in Table 4. According to these data the canopy trapped during the period examined 171.35–231.91 $kg \cdot ha^{-1} \cdot veg.\ season^{-1}$ of aerosols, increasing by this amount the access of inorganic dust to the ecosystem. This is a significant value when taking into consideration that gravitational dust fall in that period was 252.69–314.64 $kg \cdot ha^{-1} \cdot veg.\ season^{-1}$. Thanks to trapping of aerosols the amount of inorganic dust falling to the forest floor during the vegetation season increased almost twice – from 54.46 to 91.78%.

The trapping of aerosols by the canopy to such an extent gave rise to a question, to what degree this process modifies the input of elements from the atmosphere to the ecosystem.

5. THE IMPORTANCE OF INORGANIC AEROSOLS FOR NITROGEN INPUT FROM THE ATMOSPHERE TO THE FOREST ECOSYSTEM

Undoubtedly, 50 to 90% greater amount of inorganic dust reaching forest floor, due to trapping of aerosols by the canopy had to affect the input of elements from the atmosphere to the ecosystem. Earlier investigations and shown that inorganic dust of

industrial origin on this area was the main source of nitrogen from the atmosphere (K w i e c i e ń 1986). Thus, it could be expected that aerosols trapped by the canopy zone would be significant in the formation of the input of this element to the ecosystem.

In calculations describing the role of aerosols for nitrogen input, results of earlier investigations were used. (K w i e c i e ń 1986), and according to nitrogen content the chemical composition of inorganic dust falling gravitationally from the atmosphere and of aerosols trapped by experimental sets, was identical. Thus, it could be assumed that aerosols trapped by the canopy would have similar concentrations of this element as the gravitationally falling dust. And it was assumed that concentration of insoluble nitrogen forms in aerosols was identical as in dust, and was 0.37 to 0.57%, according to the season. On the other hand, for the concentration of soluble nitrogen forms in aerosols, an equivalent coefficient of leaching this element from gravitationally falling inorganic dust was assumed $7.11 \pm 2.87\%$. An additional, aerosol input of nitrogen to the ecosystem was obtained by multiplying proportion of soluble and insoluble nitrogen forms in aerosols by their amount trapped by the canopy during the vegetation season.

Table 5. Aerosol nitrogen input to forest ecosystem (Pino-Quercetum) in the Rybnik Coal Region ($\bar{x} \pm SD$) ($kg \cdot ha^{-1} \cdot veg.\ season^{-1}$)

Year	Aerosols trapped by the canopy	Nitrogen input in aerosols			Total nitrogen input with rain and dust fall from the atmosphere*
		in unsoluble form	in soluble form	total	
1981	171.35	0.98	12.18	13.16 ± 4.92	22.55 ± 1.18
1982	231.91	0.86	16.49	17.35 ± 6.66	8.57 ± 0.43
1983	194.39	0.89	13.82	14.71 ± 5.58	14.65 ± 0.92

*Data from paper by K w i e c i e ń (1986).

Results of calculations are given in Table 5. The show that trapped aerosols provided the ecosystem additionally with $13.16-17.35\ kg \cdot ha^{-1}$ of nitrogen in the vegetation season, and the soluble form of the element dominated – $12.18-16.49\ kg \cdot ha^{-1} \cdot veg.\ season^{-1}$. At the same time the total from rain and dust from the atmosphere was $8.57-22.55\ kg \cdot ha^{-1}$ of nitrogen. When comparing these two values one has to appreciate the aerosols as a source of this very important nutrient. Mean seasonal access of nitrogen in aerosols ($15.07 \pm 9.99\ kg \cdot ha^{-1}$) equals quntitatively the mean seasonal access of this element in rain and inorganic dust ($15.26 \pm 1.56\ kg \cdot ha^{-1}$). There could have been also a situation (season of 1982), when the calculated additional nitrogen input due to trapping the aerosols could exceed considerably the access of this element in rain and gravitationally falling dust. In such case, the comission of aerosol nitrogen would decrease almost twice its input from the atmosphere. This prove beyond any doubt that trapping of aerosols by the canopy in zones with high air dustiness is very important for the input of elements from the atmosphere to the ecosystem.

6. DISCUSSION

In papers on cycling of elements in ecosystems the input from atmosphere in the form of aerosols, small particles floating in the air and depositing on plants, is frequently mentioned (C a r l i s l e et al. 1966, E r i k s s o n 1966, W h i t e 1969). But this indicates that such phenomenon where aerosols are trapped by vegetation exist and their possible consequences.

The aerosol input of nutrients to ecosystems has been discussed by S w a n k and H e n d e r s o n (1976), H e n d e r s o n et al. (1977) L i n d b e r g and H a r r i s (1981). They have recorded the presence of small inorganic particles in the atmosphere, their settlement on plants, but not quantitatively. Chemical analyses of aerosols indicated the possibility of enriching rain water in elements, bud did not allow to determine the amount of nutrients reaching by this way the ecosystems.

Experiments presented by N i h l g ä r d (1970), W h i t e and T u r n e r (1970) and K w i e c i e ń (1986) are a direct proof that there is an aerosol input of elements from the atmosphere, and also that small particles are trapped by vegetation. A statistically significant increase of inorganic dust fall under artificial dust traps has been even recorded (K w i e c i e ń 1986). And although these papers have shown that trapping of aerosols amounts to greater input of elements from the atmosphere, the method applied did not allow to determine the amount of trapped aerosols and thus total access of elements to ecosystems.

The papers on the amount of aerosols depositing on plants usually are based on laboratory or field experiments (C h a m b e r l a i n and C h a d w i c k 1966, W h i t e and T u e r n e r 1970, S c h i n n 1978, S e h m e l 1980, G m u r et al. 1983a, 1983b). They concern the artificially produced aerosols, and so the results can be hardly related to various particles in the atmosphere. An additional difficulty is the fact that deposition on leaves varies greatly, depending on size and shape of particles, wind velocity, moisture or viscosity of trapping area (C h a m b e r l a i n 1967, A y l o r and P a r l a n g e 1975) and leaves setation (W h i t e and T u r n e r 1970, W e d d i n g et al. 1975). Thus it is extremely risky to use experimentally obtained, under artificial conditions, conversion factors for trapping aerosols for real processes as W h i t e and T u r n e r (1970) have done.

An example of indirect methods of estimating the input of nutrients in aerosols and gases together can be the paper by M a y e r and U l r i c h (1974). The authors have concentrated on soluble compounds they contain and the methods used did not allow to determine the amount of small particles trapped by the canopy. As a measure of aerosol and gas input of elements the enrichment of rain water in nutrients while passing through the canopy zone in winter, i.e. inactive period for the majority of plants, has been assumed. It allows to calculate the theoretical access by this way of elements all the year round. This method seems to be controversial for two reasons. First of all, applied for deciduous forests, it does not take into consideration that the presence of leaves in the vegetation season increases significantly the aerosol trapping area as compared with the winter period. Thus, it can not be assumed that the amount of trapped particles is identical for the whole year. Next, this method is not universal as

it can not be applied for coniferous forests, for which the winter season can not be considered as entirely inactive.

W i m a n and Ä g r e n (1985), W i m a n et al. (1985), W i m a n and L a n n e f o r s (1985) have a different approach to studies on the amount of trapped aerosols. On the basis of over fifty parameters characterising aerosol particles, their movement and concentration in the atmosphere, movement and air humidity, horizontal and vertical structure of forest, surface area of leaves, they have elaborated a mathematical model of aerosol access of elements for a coniferous forest. However, this model has not been verified under field conditions as regards its usefulness for quantitative estimation of aerosol trapping by forest ecosystem. At the same time a necessity to record constantly many parameters makes this method a greatly time-consuming one.

Thus, none of the papers presents an direct method for determining the amount of aerosols trapped by ecosystems under real conditions. So it seemed necessary to prepare a simple direct method of determining this parameter. Having the data on the amount of aerosols trapped by vegetation and their chemical composition, one can easily determine how many and what elements they provide for the ecosystem.

This method seems closer to reality by calculating the amount of aerosols trapped by the canopy only on the basis of field investigations under real conditions. Another positive aspect is that simple apparatus are required and it is not too sofisticated.

The methods applied allow to calculate directly from empirical data the amount of aerosols trapped by the canopy of a specific ecosystem in the vegetation season. Thus obtained values: $171.35-231.91\ kg \cdot ha^{-1} \cdot veg.\ season^{-1}$ prove the best the extension of this phenomenon, which has been treated as a marginal one. Aerosols trapped by ecosystems were on the average 40.52% of all inorganic dust from the atmosphere. These data are from the highly industrial Rybnik Coal Region.

The considerable range of the phenomenon described was not without influence on the access of elements from the atmosphere to the ecosystem. In the earlier publication it had been shown how an important carrier of elements – in their soluble and insoluble form – is the inorganic dust (K w i e c i e ń 1986). Thus obtained coefficient of nitrogen leaching from dust and mean concentration of its insoluble forms in the dust allowed to calculate the amount of this nutrient reaching the ecosystem thanks to trapped aerosols. This amount was between 13.16 and $17.35\ kg \cdot ha^{-1} \cdot veg.\ season^{-1}$, whereas total nitrogen input from atmosphere on the unforested area was $8.57-22.55\ kg \cdot ha^{-1} \cdot veg.\ season^{-1}$. A comparison of these two values proves the significance of inorganic aerosols as an additional source of nutrients important for the ecosystem.

L i k e n s et al. (1977) have found similar results in studies on watersheds. On the basis of detailed ecosystem budgets they found the existence of an additional nitrogen access to the watershed, not included in investigations. It was about $14.2\ kg \cdot ha^{-1} \cdot year^{-1}$ and its probable source was the aerosol and gas input of the element.

Data on the aerosol-gas input obtained by M a y e r and U l r i c h (1974, 1977), seem to be too low as compared with data presented here and also lower than it might be expected from the conclusions of L i k e n s et al. (1977). At a similar

nitrogen access in solutions from the atmosphere — of the order 21.8 – 30.8 kg · ha^{-1} · · year^{-1} — their aerosol-gas input is only 3.6 – 6.2 kg · ha^{-1} · year^{-1}. This seems to be caused by indirect methods of estimating this input of elements. The authors have assumed the coefficient of enrichment of rain water when passing through the canopy in winter as characteristic for the vegetation season. In the case of ecosystems with the dominance of deciduous trees this assumption is quite optional as the trapping surface in these forests in winter is much smaller than in the vegetation season. Thus, also the amounts of trapped aerosols can be smaller than in the other part of the year.

The data on trapping of aerosols by the canopy presented here are not the total amount trapped by the ecosystem. It should be remembered that similar functions, although to a smaller extent, can be played by shrub and herb layers. Thus the values of trapping of aerosols by the canopy may be slightly lower as compared to the amount of aerosols trapped by the whole forest ecosystem.

The results presented here are an argument in favour of studies on aerosol input of elements to forest ecosystems. The phenomenon of trapping aerosols seems to be an extremely significant one, changing basically the image of elements input from the atmosphere. Omission of this nutrient access, especially on highly industrialized areas with high air dustiness, may cause errors in calculations of the balance of elements in ecosystems and thus incorrect interpretation of natural processes.

7. SUMMARY

The trapping of inorganic aerosols from atmosphere by the canopy of the Pino-Quercetum association, in the highly industrial Rybnik Coal Region has been investigated.

Data proving that inorganic aerosols are a lighter fraction of inorganic dust and their chemical composition does not differ from the gravitationally falling heaver fraction, have bees used here (K w i e c i e ń 1986). It has been assumed that both fractions of inorganic dust reaching the ecosystem, may partly settle in the canopy zone — mainly on leaves — and partly fall to the forest floor. The total of these two parameters provides a total amount of inorganic dust reaching the ecosystem. It it is higher than the gravitational dust fall from atmosphere, it may be assumed that aerosols are then trapped by the canopy.

The only difficulty in calculating it was the fact that under the canopy not only the inorganic dust fall (C_2) was recorded. Also particles of organic origin (O) were found, and so the value determined was the mixed dust fall on forest floor (M). O was calculated using differences in carbon concentration for organic and inorganic dust (equation (5)). Then it was retracted from mixed dust fall recorded in the area, obtaining thus the amount of inorganic dust falling on forest floor. The above method for estimating the amount of aerosols trapped by the canopy of the forest ecosystem is described by equation (3).

The data on the gravitional inorganic dust fall from atmosphere (D) are taken from an earlier publication (K w i e c i e ń 1986). Its value was 252.69 – 314.69 kg · ha^{-1} · veg. season^{-1} (Table 3).

Mixed dust dall (M) recorded under the canopy was 439.04 – 485.45 kg · ha^{-1} · veg. season^{-1} (Table 2). Inorganic dust in this mixture fluctuated between 366.91 and 395.11 kg · ha^{-1} · veg. season^{-1} (Tables 2, 4). Inorganic dust fall (O), 15.15 – 22.0% mixed dust, was also high: 66.51 – 103.47 kg · ha^{-1} · veg. season^{-1} (Table 2).

Dust deposition on 1 g of leaf is a highly differentiated parameter, both among species as for the same species in successive research seasons (Table 3). Inorganic dust access from leaves with litter fall was calculated by multiplying dust deposition in mg per 1 g of leaf by leaf fall for a given species during the vegetation season (Table 3). Despite the differences in deposition rate and leaf fall, total access of inorganic

dust to forest floor on leaf fall of all tree species (L_2) was similar in both investigated seasons – 109.24 and 117.69 kg·ha^{-1} (Tables 3, 4).

On the basis of the above data the amount of inorganic aerosols trapped by the canopy during the vegetation season were estimated by means of equation (3) (Table 4). This parameter fluctuated between 171.35 and 231.91 kg·ha^{-1}. Aerosols were on the average 40.52% of total inorganic dust reaching the ecosystem from the atmosphere.

It has been already found that in this industrial region dust of inorganic origin is of the greatest significance for the formation of the input of nitrogen from the atmosphere (K w i e c i e ń 1986). Thus it has been expected that aerosols, as their lighter fraction, trapped in considerable amounts by input shall affect the access of this element from the atmosphere. The aerosols provide additionally to the ecosystem 13.16 – 17.35 kg·ha^{-1} of nitrogen during the vegetation season (Table 5). Its mean input in aerosols (15.07 ± 9.99 kg·ha^{-1}·veg. season^{-1}) is equal in quantity to mean access of this nutrient in rain and inorganic dust falling gravitationally together (15.26 ± 1.56 kg·ha^{-1}·veg. season^{-1}).

8. POLISH SUMMARY

Badano przechwytywanie aerozoli nieorganicznych z atmosfery przez korony drzew w zespole *Pino-Quercetum* w regionie silnie uprzemysłowionym (Rybnicki Okręg Węglowy).

W pracy wykorzystano dane świadczące o tym, że aerozole nieorganiczne stanowią lżejszą frakcję pyłów nieorganicznych i pod względem składu chemicznego nie różnią się od ich cięższej frakcji – opadającej grawitacyjnie (K w i e c i e ń 1986). Założono, iż obie frakcje pyłów nieorganicznych docierające do ekosystemu mogą częściowo osadzać się w strefie koron drzew – głównie na listowiu – a częściowo opadać na dno lasu. Sumując oba parametry otrzymano całkowitą ilość pyłów nieorganicznych dochodzących do ekosystemu. Jeżeli suma ta jest większa od grawitacyjnego opadu pyłu z atmosfery, to można przypuszczać, że zachodzi tu zjawisko przechwytywania aerozoli przez korony drzew. Wartość, o jaką wzrośnie dojście pyłów nieorganicznych do ekosystemu, jest miarą procesu przechwytywania aerozoli przez strefę koron.

Jedyną trudność w obliczaniu tej wartości stanowił fakt, iż pod koronami drzew rejestrowano nie tylko opad płynów nieorganicznych (C_2). Z koron drzew padały na dno lasu także cząstki pochodzenia organicznego (O), a zatem oznaczaną w terenie wielkością jest opad pyłu mieszanego na dno lasu (M). Wartość parametru O obliczano wykorzystując różnice w koncentracji węgla między pyłem organicznym i nieorganicznym (równanie (5)). Następnie odjęto ją od opadu pyłu mieszanego rejestrowanego w terenie, otrzymując w ten sposób ilość pyłów nieorganicznych opadających na dno lasu. Przedstawioną powyżej metodą oceny ilości aerozoli przechwytywanych przez korony drzew ekosystemu leśnego opisuje równanie (3).

Dane dotyczące grawitacyjnego opadu pyłu nieorganicznego z atmosfery (D) zaczerpnięto z wcześniejszego opracowania (K w i e c i e ń 1986). Wartość tego parametru kształtowała się na poziomie 252,69 do 314,64 kg·ha^{-1}·sez. weg.$^{-1}$ (tab. 3).

Opad pyłu mieszanego (M) rejestrowany pod koronami drzew wynosił 439,05 do 485,45 kg·ha^{-1}·sez. wg.$^{-1}$ (tab. 2). Udział pyłów nieorganicznych w tej mieszaninie wahał się od 366,91 do 395,11 kg·ha^{-1}·sez. weg.$^{-1}$ (tab. 2, 4). Opad pyłu nieorganicznego (O), stanowiący 15,15 do 22,0% pyłu mieszanego, także osiągał dość znaczne wartości – 66,51 do 103,47 kg·ha^{-1}·sez. weg.$^{-1}$ (tab. 2).

Stwierdzono, że osadzanie pyłów na 1 g liścia jest parametrem silnie zróżnicowanym, zarówno między gatunkami, jak i dla tego samego gatunku w kolejnych sezonach badawczych (tab. 3). Dojście pyłów nieorganicznych osadzonych na listowiu wraz z opadem ściółki obliczano mnożąc osadzanie pyłów w mg na 1 g liścia przez wielkość opadu liści dla danego gatunku w sezonie wegetacyjnym (tab. 3). Pomimo występujących różnic w wielkości osadzania i opadu liści, sumaryczne dojście pyłów nieorganicznych do dna lasu na opadającym listowiu wszystkich gatunków drzew (L_2) było podobne w obu badanych sezonach – 109,24 i 117,69 kg·ha^{-1} (tab. 3, 4).

Na podstawie przedstawionych powyżej danych oszacowano, przy użyciu równania (3), ilość aerozoli nieorganicznych przechwytywanych przez korony drzew w sezonie wegetacyjnym (tab. 4). Wartość tego

parametru kształtowała się na poziomie 171,35 do 231,91 kg · ha^{-1}. Aerozole stanowiły średnio 40,52% całkowitej ilości pyłów nieorganicznych docierających do ekosystemu z atmosfery.

We wcześniejszym opracowaniu stwierdzono, iż w tym uprzemysłowionym regionie pyły pochodzenia nieorganicznego odgrywały dominującą rolę w kształtowaniu dopływu azotu z atmosfery (K w i e c i e ń 1986). Spodziewano się zatem, że i aerozole — będące ich lżejszą frakcją — zatrzymywane w znacznych ilościach przez korony drzew nie pozostaną bez wpływu na wielkość dojścia tego pierwiastka z atmosfery. Obliczono, iż aerozole dostarczały dodatkowo do ekosystemu od 13,16 do 17,35 kg · ha^{-1} azotu w sezonie wegetacyjnym (tab. 5). Średni jego dopływ w aerozolach (15,07 $\pm$ 9,99 kg · ha^{-1} · sez. weg.$^{-1}$) był ilościowo równoważny średniemu dojściu tego biogenu w deszczu i pyle nieorganicznym opadającym grawitacyjnie łącznie (15,26 $\pm$ 1,56 kg · ha^{-1} · sez. weg.$^{-1}$).

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