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RESPONSE REACTION OF CONIFERS TO ALKALINE DUST POLLUTION. CHANGES IN GROWTH

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Abstract. The influence of different levels of alkaline dust pollution from a cement plant on the growth of Norway spruce and Scotch pine is described. Through mediating factors like alkalization of soil, ground water, and precipitation, and alterations in metabolism, inhibition of the growth of shoots and needles, decrease of fresh and dry mass of needles, and reduction of radial increment of trees were established under the long-term impact of cement dust pollution at concentrations of 1000—2400 $g \cdot m^{-2} \cdot yr^{-1}$. In alkalized environment the measured parameters of trees are in negative correlations with the increase of pH, K, and Ca increase in the soil, ground water, and precipitation. The growth of Scotch pine may be stimulated by lower concentrations than 1000 $g \cdot m^{-2} \cdot yr^{-1}$ of cement dust. No stimulating effect of dust was found on Norway spruce.

Key words: air pollution, cement dust, Scotch pine, Norway spruce, growth, biomass, radial increment, North Estonia.

INTRODUCTION

There are numerous comprehensive reviews on the responses of conifers to elevated levels of atmospheric SO_2, NO_x, CO_2, O_3, etc. (McLaughlin et al., 1982; Norby, 1989; Popovicheva et al., 1989; Chapelka et al., 1989). The studies suggest that often these pollutants result in deviations in the functions and structure of trees.

Precise and accurate prediction of the response of trees to environmental changes is hindered by the lack of experimental data on the reaction of forest trees to alkalization of environment, both on theoretical and practical level. The role of industrial dust in disturbing the functions of forest ecosystems is regarded as secondary. However, its effect may be neutral, stimulating, or toxic depending on the chemical composition, pH, and concentration of dust (Sporek, 1983).

Dust emitted by cement industries is regarded as a neutral or stimulating factor as it does not cause necroses or chloroses of the assimilative organs of plants (Sporek, 1983; Braniewski & Chrzanowska, 1988). However, studies have also shown that cement dust may cause alkalization of the environment, accompanied by changes in the physiological state of plants. A high technogenic load complicates the mineral nutrition process which, in its turn, changes the mineral composition and cell membrane permeability of plants, followed by disturbances in the functioning of enzymes, in the metabolism of carbohydrates, in the content of amino acids, etc. (Lecrenier & Piquer, 1956; Lal & Ambasht, 1982; Mandre, 1988). In addition, cement dust on assimilative organs changes light, water, and temperature regimes in plants (Eveling, 1969; Fluckiger et al., 1978; Guggenheim et al., 1980) and affects the intensity of photosynthesis and pigment content in leaves (Auclair, 1977; Borka, 1980; Mandre et al., 1992; Mandre & Tuulmets, 1993). Changes in plant metabolism must be reflected in their growth and development.

The aim of the present work was to study prolonged effects of alkaline dust from a cement plant in North-East Estonia (Kunda) on changes in the chemical composition of the forest ecosystem and in the morphological character of *Pinus sylvestris* L. and *Picea abies* L.

MATERIALS AND METHODS

Investigations were carried out in 1987—93 on sample plots situated at different distances from the emission source and affected by different quantities of alkaline (pH 12.3—12.6) dust pollutants from the cement plant. Permanent sample plots (0.05 ha) of the similar forest site and soil types were selected from natural forests for ecomorphological investigation. Data on the location of forest sample plots, forest site type, stand age, site quality class, etc. are given in Tables 1 and 2. The length of the transect is about 50 km within the distance of 30—38 km to the west and 12 km to the east from the emission source (Fig. 1). Control sample plots were situated on the relatively unpolluted territory of Lahemaa National Park, 30—38 km to the west from the cement plant (Mandre et al., 1992). Six to ten 75—90-year-old trees of Scotch pine and Norway spruce from each sample plot in forest and 60—80-year-old trees on open land on the transect were chosen for study.

Numerous measurements were made including the length of shoots and needles, fresh and dry mass of 100 needles, and the density of needles on shoots. Branches were taken from the southern side of each tree crown. Shoots and needles were cut and arranged according to their age and location on branches. Sampling of needles and shoots for morphological investigations was carried out in August—September, the period when the organs of the current year ceased to grow.

Annual tree-ring increments can be related to changes in the chemical, physiological, or biological character of the tree (McLaughlin et al., 1982; Pärn, 1990). For determining the radial increment at the southern and northern sides of the stem, increment cores were taken from ten trees on each plot at the height of 1.3 m.

The data of comprehensive analyses of needles, shoots, and stems provided a basis for determining the decrease or increase in the growth of conifers.

Physical and chemical properties of the growth conditions were investigated to get auxiliary information for interpreting deviations in the growth of conifers. The accumulation of dominant elements of dust (Ca, K, Mg, Mn, Fe, Al) and the pH of the soil (humus horizon), ground water, and precipitation were analysed at the Estonian State Centre of Agricultural Chemistry and in the Laboratory of Horticulture at TERG Ltd. Dust concentration in the air was analysed by the Central Laboratory of Environmental Research.

The correlation coefficients r (Pearson R) and the significance of correlations p between the geochemical characteristics of the environment and morphological parameters of trees were calculated using the package STATGRAPHICS.

Table 1

Average characteristics of the investigated stands of Norway spruce at different distances from the cement plant

Location of sample plot*	Distance, km; direction	Forest type	Composition of trees	No. of trees per ha	Age, yr	Site quality class	Stand density	Height, m	Breast height diameter, cm	Density of under-storey
1	38 W	*Ox—My*	*9Pa1Ps*	580	85	II	0.7	22	31	moderate
2	30 W	*My*	*8Pa2Ps+Be*	630	75	II	0.7	20	26	moderate
3	10 W	*My*	*8Pa2Ps*	540	85	II	0.7	22	24	slight
4	6 W	*Ox—My*	*9Pa1Ps*	500	90	II	0.8	23	30	slight
5	3 W	*Ox—My*	*9Pa1Ps+Be*	570	90	II	0.8	24	24	moderate
6	2 W	*Ox—My*	*10Pa+Ps*	660	80	II	0.8	22	24	slight
7	1.5 E	*Ox—My*	*9Pa1Pt+Ps*	610	80	II	0.7	21	31	slight
8	2.5 E	*Ox—My*	*8Pa2Ps*	640	75	II	0.7	19	27	slight
9	5 E	*Ox—My*	*8Pa1Ps1Be*	720	75	II	0.8	22	28	slight
10	12 E	*Ox—My*	*8Pa2Ps*	770	75	II	0.8	23	31	moderate

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* See Fig. 1;

Ox—Oxalis, My—Myrtillus, Pa—Picea abies L., *Ps—Pinus sylvestris* L., *Be—Betula* sp., *Pt—Populus tremula.*

Table 2

Average characteristics of the investigated stands of Scotch pine at different distances from the cement plant

Location of sample plot	Distance, km; direction	Forest type	Composition of trees	No. of trees per ha	Age, yr	Site quality class	Stand density	Height, m	Breast height diameter, cm	Density of under-storey
1	38 W	*Ox—My*	9*Ps*1*Pa*+*Be*	650	75	II	0.7	21	28	moderate
2	30 W	*My*	10*Ps*+*Pa*	710	75	II	0.7	20	26	moderate
3	10 W	*My*	8*Ps*2*Pa*	580	85	II	0.7	22	24	slight
4	6 W	*Ox—My*	9*Ps*1*Pa*+*Be, Pt*	640	80	II	0.8	22	24	moderate
5	3 W	*Ox—My*	9*Ps*1*Pa*+*Pt*	590	90	II	0.8	23	24	moderate
6	2 W	*Ox—My*	10*Ps*+*Pa*	680	80	II	0.8	21	22	slight
7	1.5 E	*Ox—My*	10*Ps*	620	80	II	0.7	21	26	moderate
8	2.5 E	*Ox—My*	10*Ps*+*Pa*	660	75	II	0.7	20	29	moderate
9	5 E	*Ox—My*	9*Ps*1*Pa*	700	75	II	0.8	21	26	moderate
10	12 E	*Ox—My*	10*Ps*+*Pa*	690	75	II	0.7	23	30	severe

See notes to Table 1.

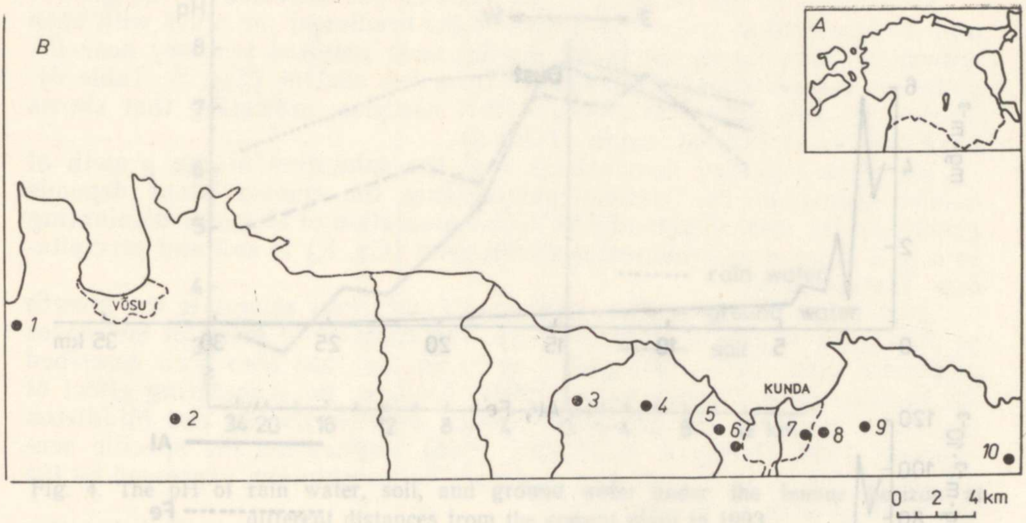

Fig. 1. The study area. *A* location in Estonia. *B* sample plots on the investigation transect: *1—2* control sample plots in Lahemaa National Park; *3—10* sample plots affected by different quantities of air pollutants.

RESULTS AND DISCUSSION

1. Peculiarities of the growth conditions of trees on sample plots

The main damaging factor for forests in the vicinity of the cement plant is apparently technological dust, which constitutes 87—91% of the total emission (Keskkond '89, 1990; Keskkond '90, 1991). The data from the cement plant laboratory and by L. Õispuu (pers. comm.) from Tallinn Technical University show that the dust from the electric filters contains predominantly the following substances: 40—50% CaO; 12—17% SiO_2; 6—9% K_2O; 4—8% SO_3; 3—5% Al_2O_3; 2—4% MgO; 1—3% Fe_2O_3. Altogether 49 elements were identified in the cement dust including Mn, Zn, Cu, Cr, V, As, Ba, Pb, etc. Dust from electric filters may have the pH value of approximately 12.3—12.6.

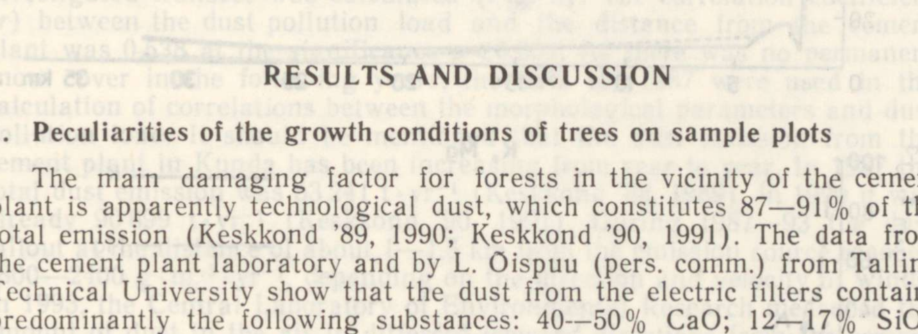

Fig. 2. Dust pollution load on the investigated transect in 1987.

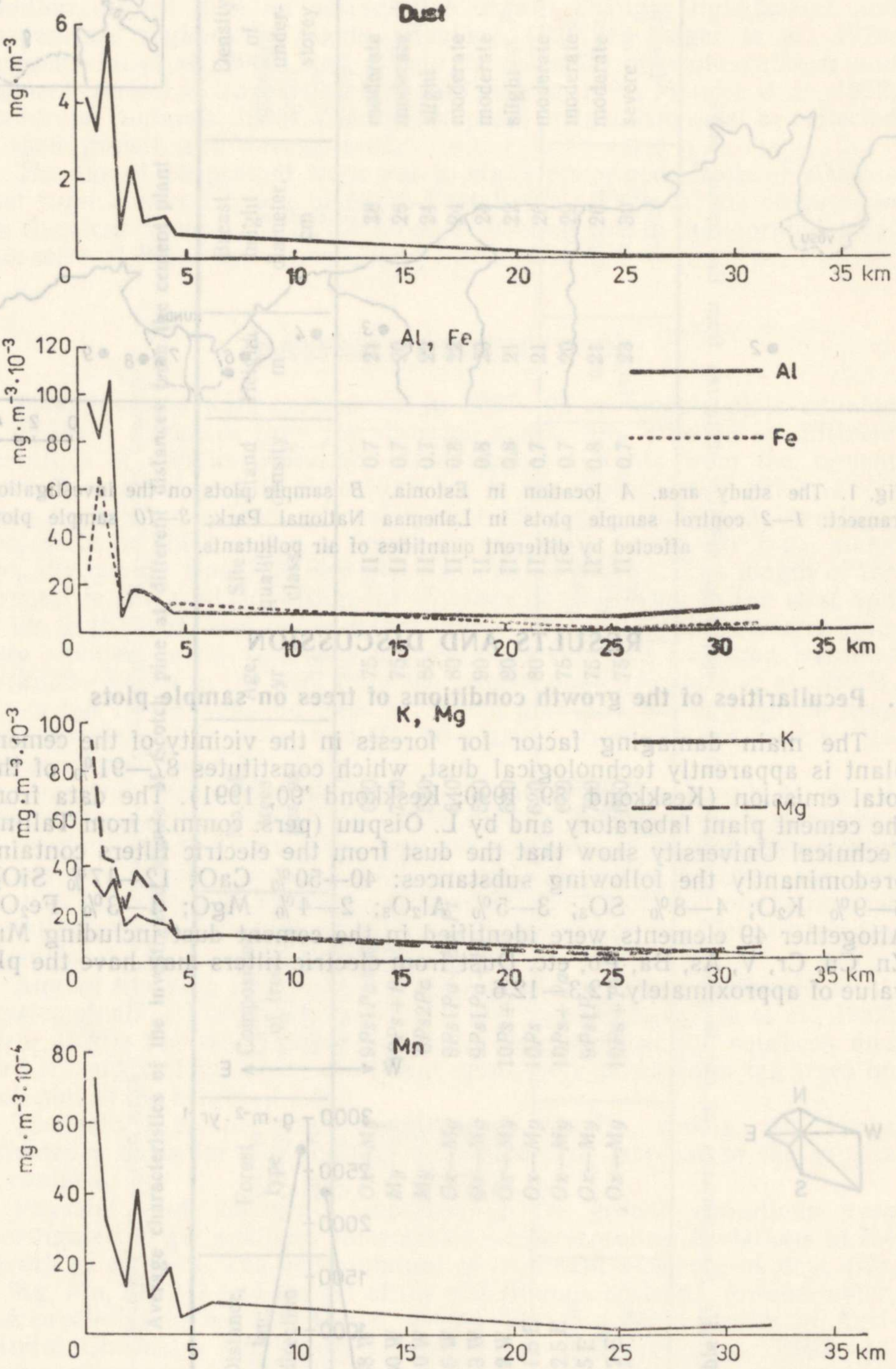

Fig. 3. The average amount of dust and chemical elements in the air on the leeward territory (Sept., Oct. 1993).

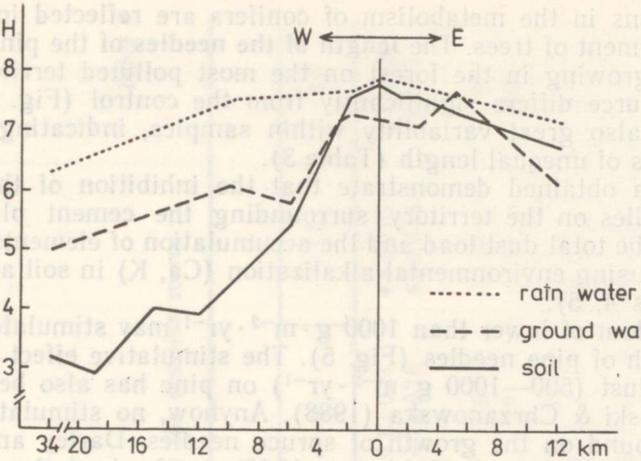

Fig. 4. The pH of rain water, soil, and ground water under the humus horizon at different distances from the cement plant in 1993.

On the bases of snow analyses from 1987 the dust load on the investigated transect was calculated (Fig. 2). The correlation coefficient (r) between the dust pollution load and the distance from the cement plant was 0.538 at the significance $p<0.001$. As there was no permanent snow cover in the following years, the data for 1987 were used in the calculation of correlations between the morphological parameters and dust pollution load. It should be mentioned that the dust emission from the cement plant in Kunda has been increasing from year to year. In 1987 the total dust emission was $53\,241\ \mathrm{t \cdot yr^{-1}}$ (Keskkond '88, 1989), in 1990 it was already $90\,699\ \mathrm{t \cdot yr^{-1}}$ (Keskkond '90, 1991). During 1987—93 the dust fallout at the distance of about 1—1.5 km from the emission source reached $1800—2400\ \mathrm{g \cdot m^{-2} \cdot yr^{-1}}$, depending on the direction and velocity of winds. In 1993, the Central Laboratory of Environmental Research measured the amount of dust in the air in different leeward directions from the cement plant and showed that the dust content at the distance of 1.5 km may exceed $5\ \mathrm{mg \cdot m^{-3}}$ (Fig. 3). High dust concentrations in the air bring about alkalization and changes in the chemical composition of precipitation. High pH values of precipitation were measured on the territory influenced by pollutants from the cement plant (approximately 7—8 during the vegetation period; Fig. 4). The pH of snow water may exceed 10 (Mandre et al., 1992).

Alkalization of the upper horizons of forest soils and ground water (Fig. 4) and accumulation of elements prevailing in dust (Ca, K, Mg, Mn, etc.) are substantial at a distance of 3—5 km and noticeable to about 15 km from the emission source (Mandre et al., 1992). The correlation coefficients (r) between the total air pollution load and pH ($r=0.68$), Ca ($r=0.89$), K ($r=0.90$), Mg ($r=0.88$) in the humus horizon of the soil on the investigation transect were found statistically at the significance level $p<0.005$.

2. Changes in the morphological parameters of conifers

Cement dust covering the needles of Scotch pine and Norway spruce has a physical and chemical effect on the trees and causes great alterations in their metabolism. Deviations depend on the age of needles and distance from pollution source (Mandre et al., 1992; Mandre & Tuulmets, 1993).

Alterations in the metabolism of conifers are reflected in the growth and development of trees. The **length of the needles** of the pines with open crowns or growing in the forest on the most polluted territory near the emission source differs significantly from the control (Fig. 5; Table 3). There was also great variability within samples, indicating that shoots have needles of unequal length (Table 3).

The data obtained demonstrate that the inhibition of the growth of conifer needles on the territory surrounding the cement plant depends greatly on the total dust load and the accumulation of elements dominating in it and causing environmental alkalization (Ca, K) in soil and precipitation (Tables 4, 5).

Dust fallout of lower than 1000 $g \cdot m^{-2} \cdot yr^{-1}$ may stimulate the growth of the length of pine needles (Fig. 5). The stimulative effect of low doses of cement dust (500—1000 $g \cdot m^{-2} \cdot yr^{-1}$) on pine has also been described by Braniewski & Chrzanowska (1988). Anyhow, no stimulating effect of dust was found on the growth of spruce needles. Darley and Middleton (Darley, 1966; Darley & Middleton, 1966) emphasized the specific sensitivity of spruce to cement dust and its alkaline solution, expressed by the inhibited growth of needles.

It is well known that the length of pine needles depends on their location in the canopy. Generally, needles on the main shoots are longer than those on the lateral shoots, needles on trees growing in the open are longer than on those growing in the forest. But the reaction of the length of spruce needles to high dust concentrations does not depend much on their location in the crown and the age of needles. However, the decrease of the length of needles of forest trees is more significant than that of the open crown (Table 6).

Many forest biologists suggest that needle discoloration in conifers may be related to forest decline (Lang & Holdenrieder, 1985; Pfeifhofer & Grill, 1987). High amounts of cement dust cause definite destruction of chlorophylls in conifer needles (Mandre, 1989; Mandre et al., 1992). Statistical analysis of our data revealed a significant correlation between the length and chlorophyll concentration of the needles of Norway spruce on the investigation transect (Chl *a*: $r=0.58$, $p<0.05$; Chl *b*: $r=0.67$, $p<0.01$; total concentration of Chl: $r=0.6$, $p<0.05$).

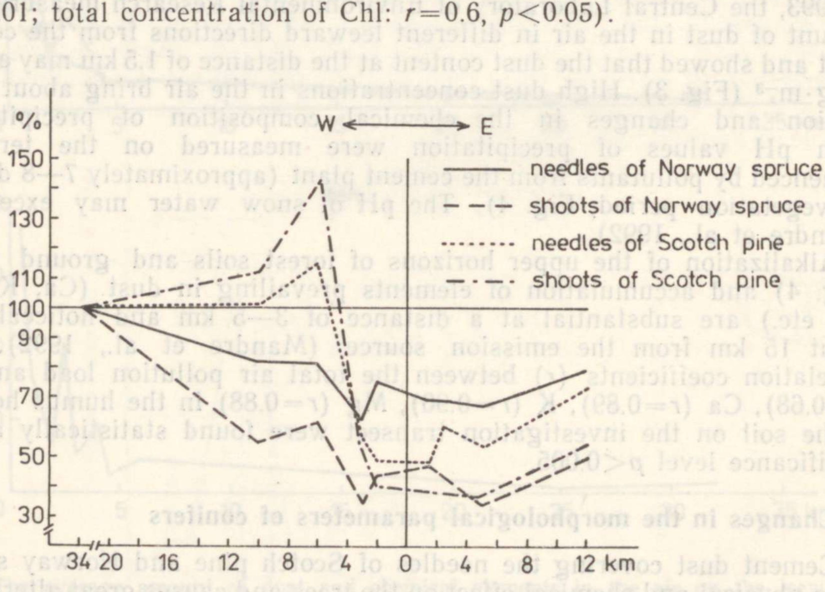

Fig. 5. The length of needles and shoots of Scotch pine and Norway spruce at different distances from the cement plant (organs of 1992, % of control).

Table 3

Needle length and its variation of open-crown Scotch pines at different distances from the emission source

Parameter	Year of formation of needles	Distance to the W, km						
		34	15	10	5	3	1.5	0.5
Length, cm	1987 1988	4.6±0.09 4.3±0.11	5.1±0.18 4.7±0.1	5.8±0.1 5.7±0.09	4.8±0.19 4.6±0.14	5.1±0.21 4.7±0.16	4.4±0.02 4.5±0.14	3.9±0.06 2.9±0.1
Coefficient of variation, %	1987 1988	8 21	11 25	11 22	10 21	5 10	19 23	27 46

Table 4

Correlation between needle length and its variation of open crown Scotch pine, and characteristics of growth conditions on the investigation transect in 1987—88 and its significance

Characteristics of growth conditions		Length of needles		Coefficient of variation	
		r	p	r	p
Dust load		−0.77	<0.01	0.84	<0.001
Soil:	Ca	−0.81	<0.001	0.88	<0.001
	K	−0.74	<0.01	0.78	<0.01
	Mg	−0.8	<0.01	0.73	<0.01
Snow:	pH	−0.65	<0.05	0.68	<0.05
	Ca	−0.64	<0.05	—	—
	K	−0.73	<0.01	0.68	<0.05
	S	−0.64	<0.05	—	—
Rain water:	Ca	−0.71	<0.05	0.91	<0.001
	K	−0.76	<0.01	0.98	<0.001
	S	−0.8	<0.01	0.98	<0.001

Table 5

Correlation between the length of needles formed in 1992 and characteristics of growth conditions and its significance in forest sample plots on the investigation transect

Characteristics of growth conditions		Length of needles			
		Scotch pine		Norway spruce	
		r	p	r	p
Dust load		−0.68	<0.01	−0.56	<0.05
Soil:	pH	−0.87	<0.001	−0.86	<0.001
	Ca	−0.54	<0.05	—	—
	K	−0.58	<0.05	−0.66	<0.001
Ground water:	pH	−0.87	<0.001	−0.9	<0.001
	Ca	−0.78	<0.01	−0.67	<0.01
	K	−0.64	<0.001	−0.55	<0.05
	S	−0.69	<0.01	−0.69	<0.01
Snow:	pH	−0.75	<0.001	−0.9	<0.001
	Ca	−0.63	<0.01	−0.91	<0.001
	K	−0.71	<0.001	−0.88	<0.001
	S	−0.64	<0.01	−0.71	<0.001
Rain water:	pH	−0.66	<0.01	−0.96	<0.001
	Ca	−0.88	<0.001	−0.74	<0.01
	K	−0.68	<0.01	—	—

Table 6

Influence of cement dust on the length of needles of different ages

Type of shoots, location in tree crown	Age of needles	Length of needles					
		Scotch pine			Norway spruce		
		Control, cm	1.5—2.5 km E from the cement plant		Control, cm	1.5—2.5 km E from the cement plant	
			cm	% of control		cm	% of control
Forest trees							
Main shoot	Cy	5.1±0.18	3.2±0.17	63	1.3±0.08	0.9±0.03	69
	1y	5.4±0.19	3.6±0.19	67	1.3±0.12	0.9±0.05	69
	2y	5.5±0.21	3.7±0.21	67	1.4±0.07	0.9±0.06	64
Lateral shoot	Cy	4.7±0.12	2.5±0.12	53	1.4±0.25	0.9±0.05	57
	1y	4.9±0.23	3.1±0.2	63	1.4±0.07	0.9±0.05	64
	2y	4.7±0.12	3.0±0.19	64	1.3±0.03	1.0±0.05	76
Open-crown trees							
Main shoot	Cy	5.4±0.55	4.3±0.2	77	1.4±0.04	1.1±0.11	79
	1y	5.9±0.46	4.7±0.28	80	1.5±0.07	1.2±0.05	80
	2y	5.7±0.01	4.5±0.05	79	1.4±0.09	1.2±0.05	86
Lateral shoot	Cy	5.0±0.13	2.9±0.4	58	1.3±0.04	1.2±0.03	85
	1y	5.0±0.22	4.2±0.14	84	1.4±0.07	1.2±0.09	93
	2y	5.9±0.07	3.9±0.21	66	1.5±0.05	1.2±0.23	80

Cy—current year needles, formed in 1993;
1y, 2y—one- and two-year-old needles, formed in 1992 and 1991.

Table 7

Average morphological parameters of Scotch pine and Norway spruce on the control plot and in the vicinity of the cement plant (1990, 1991, 1992)

Sample plot, parameter	Scotch pine		Norway spruce	
	Main shoots	Lateral shoots	Main shoots	Lateral shoots
Control				
Length of shoots, cm	9.83±0.96	6.23±0.48	8.62±0.75	6.7±0.27
Length of needles, cm	5.33±0.18	4.79±0.12	1.28±0.28	1.33±0.06
Fresh mass of 100 needles, g	4.72±0.47	3.87±0.33	0.77±0.03	0.71±0.03
Dry mass of 100 needles, g	2.06±0.2	1.71±0.14	0.31±0.02	0.3±0.02
Dry matter of needles, %	43.61±0.64	44.15±0.83	42.69±0.66	41.83±0.35
1.5—2.5 km from the cement plant				
Length of shoots, cm	4.63±0.39	2.73±0.24	8.1±0.47	6.19±0.19
Length of needles, cm	3.45±0.13	2.77±0.12	0.95±0.03	0.94±0.02
Fresh mass of 100 needles, g	1.94±0.13	1.52±0.09	0.73±0.01	0.64±0.001
Dry mass of 100 needles, g	0.91±0.06	0.73±0.04	0.32±0.002	0.28±0.0001
Dry matter of needles %	46.73±0.61	48.04±0.49	44.63±0.82	45.3±0.59

Table 8

Influence of dust pollution on the density of needles on the shoots of Scotch pine and Norway spruce

Species, type of shoots	Age of shoots	Control		1.5—2.5 km E from cement plant	
		No. of needles			
		per shoot	per cm	per shoot	per cm
Scotch pine					
Main	Cy	275±39	15.5±3.2	39.6±8.5	14.3±3.1
	1y	259±11	13.2±1.3	43.7±11	12.4±2.7
Lateral	Cy	187±15	18.3±0.9	43.8±4.1	14.2±1.5
	1y	117±14	12.6±0.9	49.6±5.9	15.3±1.1
Norway spruce					
Main	Cy	100±7.5	17.1±1.9	74.0±9.5	12.6±1.4
	1y	108±9.1	15.6±1.3	73.3±10	10.7±1.3
Lateral	Cy	102±8.2	17.7±2.1	65.1±8.3	14.7±1.1
	1y	109±6.8	16.7±2.1	65.0±9.9	11.3±1.4

See notes to Table 6.

Table 9

Correlation between radial increment of trees (1983—1992) and characteristics of growth conditions on the transect and its significance

Characteristics of growth conditions		Radial increment			
		Scotch pine		Norway spruce	
		r	*p*	*r*	*p*
Dust load		−0.69	<0.01	−0.84	<0.001
Soil:	pH	—	—	−0.61	<0.05
	Ca	−0.85	<0.001	−0.67	<0.01
	K	−0.75	<0.01	−0.78	<0.001
Ground water:	pH	—	—	−0.76	<0.01
	Ca	—	—	−0.91	<0.001
	K	—	—	−0.83	<0.001
	S	—	—	−0.76	<0.01
Snow:	pH	—	—	−0.7	<0.05
	Ca	−0.86	<0.01	−0.71	<0.05
	K	−0.79	<0.01	−0.83	<0.01
	S	−0.76	<0.05	−0.87	<0.01
Rain water:	pH	−0.8	<0.05	−0.83	<0.05

— no significant correlation was detected.

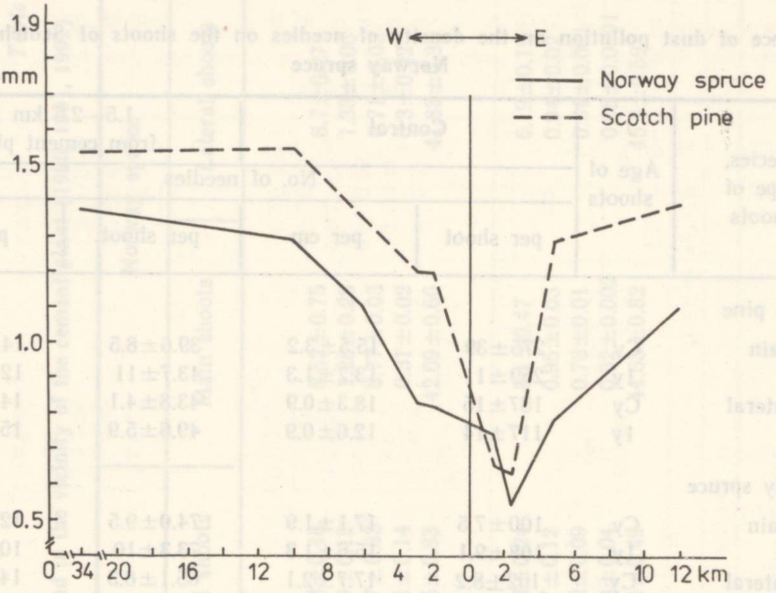

Fig. 6. Radial increment of conifers on sample plots at different distances from the cement plant (average data of 1983—1992).

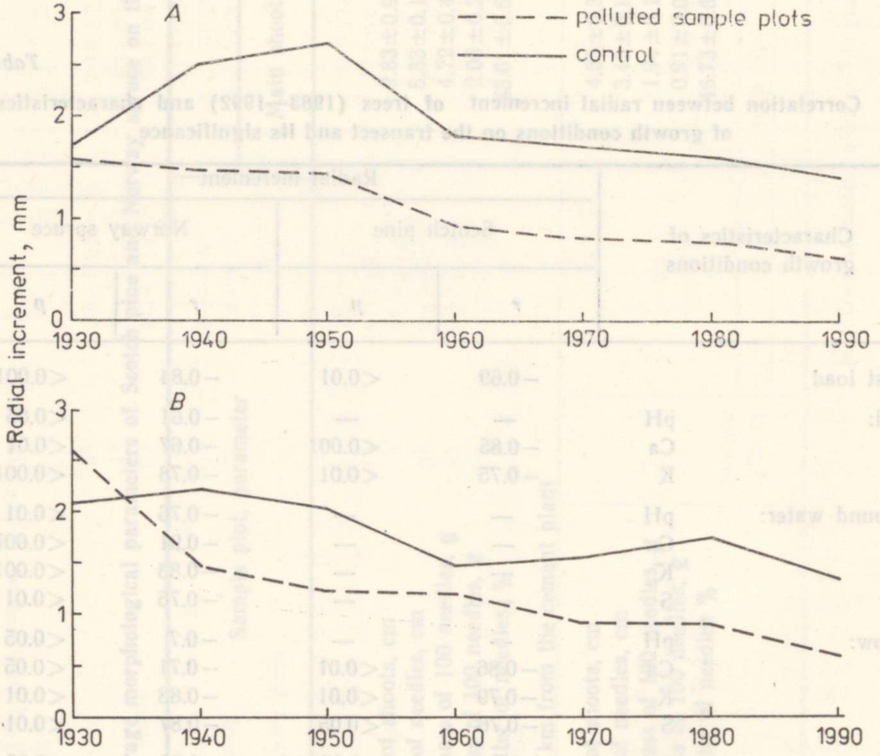

Fig. 7. Radial increment of conifers (mean of ten years) 1.5—2.5 km to the east of the cement plant and in the control plot (38 km to the west). *A* Scotch pine, *B* Norway spruce.

A decrease in needle growth in the vicinity of the cement plant is accompanied by changes in the **fresh and dry mass of the needles**. The mass of 100 pine needles in the area of high pollution in forest sample plots at a distance of 1.5—2.5 km from the plant amounts to 40—45% of that of the control. Differences in the mass of spruce needles were about 5—10% (Table 7). Compared to the control, both species show higher concentrations of dry matter under the influence of the cement factory emissions; this indicates alterations in the water regime of the organisms.

Changes in the appearance and size of the shoots are one of the symptoms of the damage caused by industrial emission to coniferous trees. Compared to needle length, the **growth of shoots** seems to be more sensitive to dust pollution (Table 7, Fig. 5). A comparison of the sensitivity of spruce and pine to dust impact shows that no essential differences exist in the depression of the growth of their shoots under high dust loads (Table 7). Other conifers are also sensitive to alkaline dust pollution. The effect of limestone dust on *Tsuga canadiensis* L. was investigated by Manning (1971), who reported an about 48% reduction in the length of new terminal growth.

On the investigated transect, the prevailing winds are from the southwest, south, and west, forming the most polluted territory towards the northeast and east from the emission centre (Mandre et al., 1992). This is also revealed in the depressed growth of needles and shoots that can be observed 2—3 times farther in the east than in the west (Fig. 5). Still, at distances of 4—5 km and more from the cement plant to the west under the relatively low concentrations of cement dust, the length of pine shoots may surpass that of the control.

The number of needles on shoots is important as regards the photosynthetic potential of the trees. Defoliation and the density of needles are parameters for assessing forest vitality. Alkaline dust from the cement plant depresses the development of shoots and reduces the number and density of needles on a shoot (Table 8). The average number of pine needles per shoot in 1993 was 79% smaller than that of the controls, the number of needles per 1 cm of a shoot had dropped 6%. In spruce these parameters were 35% and 27%, respectively.

Besides the inhibition of the growth of needles and shoots, **radial increments of trees** also showed a reduction under alkaline pollution. The reduction depended on the dust load at different distances from the emission centre (Table 9, Fig. 6). Decrease in the radial increment of Norway spruce and Scotch pine is clearly noticeable during the long period of cement production (Fig. 7). The mean radial increment of spruce in the highly polluted territory at a distance of 1.5—2.5 km to the east from the cement plant constituted 48% of the control in 1983—92, and that of pine 42%. To the west, under lower pollutant concentrations, the decrease is not so noticeable: at a distance of 2.5 km from the plant, the mean radial increment of spruce constitutes 60% and that of pine 78% of the control. Analogically to the growth of needles and shoots the radial increment of spruce and pine under anthropogenic alkalization of the environment depends on the pH value and the amount of K and Ca in soil, ground water, and precipitation on the transect (Table 9). A reduction of lateral growth by at least 18%, caused by limestone dust, was also shown for *Acer rubrum*, *Quercus prinus*, and *Q. rubra* by Brandt & Rhoades (1973).

What is the reason for the inhibition of growth? It is known that intensive lignification stops the growth of plant cells (Grand et al., 1981). We analysed the content of lignin in the needles of conifers growing near the cement plant. The results indicated that the content of lignin in the needles of Norway spruce was approximately 15—20% higher than that of the control trees. Therefore, K is one of the elements that have a stimulating effect on the formation of lignin in trees as emphasized by Mengel (1972). Our earlier works showed also that there is a rapid increase of K in spruce and pine needles under the influence of dust (Mandre, 1989, 1990, 1991). This may be one of the internal reasons for the increase in the lignin content and the inhibited growth of tree organs in a dusty and alkalized environment. However, these factors should not be regarded as the only ones inhibiting or stimulating the growth of conifers. The limiting of light penetration, changes in photosynthetic activity and mineral nutrition facilities in general are reflected in the inhibition of the growth of conifers under the impact of technogenic alkaline dust.

CONCLUSION

The results of the investigation revealed a multidirectional influence of cement dust on forest ecosystems. In natural ecosystems that have been affected by alkaline technogenic dust pollution for a long period, the growth conditions of trees (soil, ground water, precipitation) have become strongly alkaline and the surface of trees is covered with cement crusts. A decrease in the needle length and mass, shoot length, and density of needles on them is noticeable; the radial increment of conifers decreases in comparison with the trees growing in relatively unpolluted by cement dust forest stands. The amplitude of changes in the morphological parameters of Scotch pine and Norway spruce depends much on the level of technogenic load. A substantial dependence of the growth and biomass of Norway spruce and Scotch pine on the pH and the increased amounts of K and Ca of the alkalized growth substrate was established.

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