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RESPONSE REACTIONS OF CONIFERS TO ALKALINE DUST POLLUTION. CHANGES IN THE PIGMENT SYSTEM

Abstract. A comparative field study of the effect of prolonged emission of alkaline (cement) dust on 60—80-year-old Norway spruce (*Picea abies* L.) and Scotch pine (*Pinus sylvestris* L.) was carried out. The effect of various levels of dust pollution occurring at different distances from the Kunda cement plant in North-East Estonia was investigated. Through mediating factors like alkalization of environment, deficiency of light, and changes in nutrition, alterations in the content of photosynthetic pigment in conifer needles were assessed. In the zone of 0.5—1.0 km from the cement plant, where the level of dust pollution is high, a decrease in the content of chlorophylls and carotenoids was observed. The decrease was especially pronounced in the youngest needles; spruce was more sensitive than pine. The highest sensitivity to dust effect was revealed by Chl *a* and Chl *a*/Chl *b* ratio. The winter maximum of β-carotene content in pine needles arrived earlier and more rapidly in this zone than in the control sites. Farther from the pollution source the pigment accumulation in conifer needles may be even stimulated.

Key words: air pollution, cement dust, precipitation, soil, Scotch pine, Norway spruce, chlorophyll, carotenoid, North-East Estonia.

Introduction

Although the detrimental effects of air pollutants on vegetation are widely accepted nowadays, it may be difficult to identify damage in a concrete case, as the reactions of a plant are mostly unspecific and resemble those caused by other stresses. Extremely high levels of air pollution cause visually observable injuries such as necrotic lesions and chlorotic areas. Visible symptoms of injury are the result of plasmolysis, granulation or disorganization of cell contents, cell collapse or disintegration, and pigmentation of affected tissue (Mudd and Kozlowsky, 1975). These symptoms are the consequence of deep disturbances of physiological processes. At the low-dose exposure functional injuries occur mostly without visible symptoms (Skelly, 1980; Schubert, 1985). It is known that physiological and biochemical reactions are primary responses of organisms to any type of stressors. That is why physiological and biochemical methods are needed for the elucidation of invisible symptoms (metabolic deviations), for early diagnosis of emission impacts, as well as for the study of the mechanisms of pollution—plant interactions.

Forest trees provide a suitable object for the study of the toxicity of industrial emissions to plants. Having a very long ontogenetic development, trees can accumulate larger quantities of toxic substances than herbaceous plants when exposed to pollution. Because of their high sensitivity to air pollution and long-term foliar retention, conifers have often been recommended as investigation and test objects.

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Among anthropogenic air pollutants too little attention has been paid to industrial dust and its interaction with vegetation and soil. Though industrial dust pollution is of rather local effect, its overall amount is considerable, constituting approximately 10% of the total air pollution in the world (Безгулая, 1980). In Estonia dust pollution requires special attention as here dry deposition constitutes on the average even 45—50% of total air pollution (Keskkond '89, 1990; Keskkond '90, 1991).

In general, no specific visually observable air pollution injuries occur on conifer needles in the industrial territories of North-East Estonia even in the vicinity of the cement plant *Eesti Tsement* (Kunda), where the calcareous dust content accounts approximately for 87—91% of the total air pollution (Keskkond '89, 1990; Keskkond '90, 1991). Therefore, physiological and biochemical investigations are necessary to obtain objective data about the deviations of the forest ecosystems in this region. As it might prove more reasonable to avoid pollution damage than to cope with it, the state of forests should be established to work out indispensable preventive measures. The pigment content of assimilatory organs is considered as an indicator of the state, health, and also anthropogenic injuries of plants (Gowin and Goral, 1977; Dässler, 1972; Arndt, 1971; Илькун, 1978; Сергейчик, 1984).

Methods and Materials

The biochemical response reactions of plants to high levels of industrial alkaline dust pollution were studied in 1984—1992 on the territory affected by the cement plant in Kunda, North-East Estonia. Twenty-two sample plots of *Myrtillus—Oxalis* site type of mixed pine and spruce forest stands were chosen for investigation. The sample plots were situated in the vicinity of the emission source and within the distance of 30—34 km to the west and 10—13 km to the east from it (Fig. 1). We chose 60—80-year-old trees of Scotch pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* L.) for investigation. Six to ten trees from each sample plot on the transect were investigated to assess how far the impact of dust pollution reached and what were the consequences of different levels of pollution. Seasonal variation of pigments in needles was measured on the sample plots with 5—8 open-grown trees at the distances of 0.5—1.0 km and 1.5—2.0 km from the cement plant and on the unpolluted territory of Lahemaa National Park 30—34 km to the west from the cement plant. Samples of needles were taken every month during a year from the southern side of the crown at the height of 5—6 m from the ground. All the needles of the same age were removed from the shoots of each investigated tree, they were cut into small pieces and carefully mixed. Mixing is assumed to reduce the effect of variation in pigment content along the needles (Wood and Bachelard, 1969) and the individual variability of the trees (Linder, 1972). The samples from control plots in Lahemaa National Park were collected in the same way and the data were presented as an average of all investigated trees of three (*1—3*, Fig. 1) sample plots at the distance of 30—34 km from the cement plant.

For the extraction of chlorophylls and carotenoids we used 96% ethanol and measured their amount spectrophotometrically (СФ-16). This procedure seemed to be the most suitable for comparative determinations of a large number of samples and is recommended by many scientists (Gowin and Goral, 1977; Reich et al., 1986; Vernon, 1960; Гавриленко et al., 1975). For measuring the content of Mg in conifer needles the atom

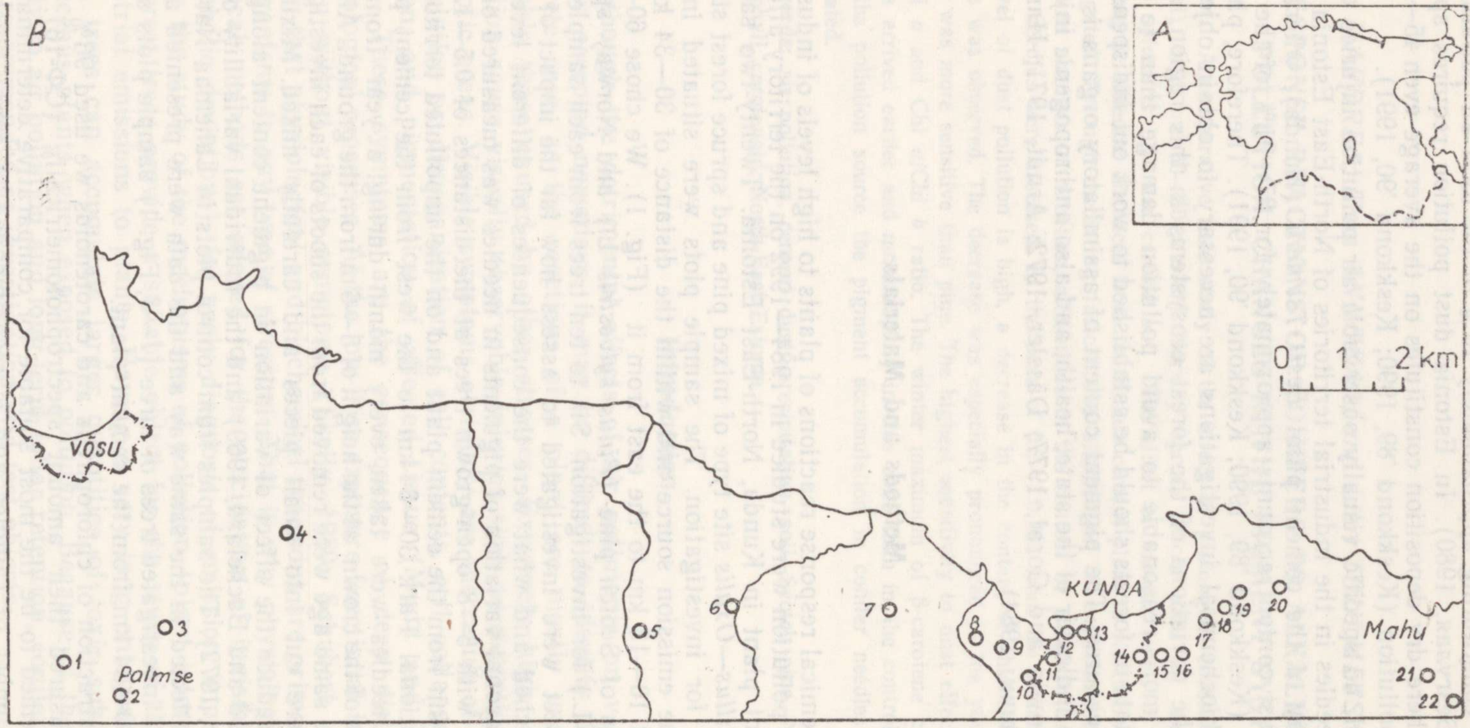

Fig. 1. The study area. *A* — location in Estonia. *B* — sample plots on the investigation transect: *1—4* — control sample plots in Lahemaa National Park; *5—22* — sample plots affected by different quantities of air pollutants.

adsorption analyser AAS-1N was used; N was measured by the method of Kjeldhal, and S by the nephelometric method with $BaCl_2$ (Руководство . . . , 1979). Growth conditions (physical and chemical properties of soil and precipitation during the vegetation period and in winter) were investigated to get auxiliary information for the interpretation of the deviations in plant organisms. The content of chemicals in soil and precipitation was analysed in the Estonian Station of Agrochemistry and in the Laboratory of Agriculture of the industrial enterprise *Terg*.

Table 1

Chemical characteristics of rain water on the control and polluted territories

(Figures above the fraction line designate average values; those under the line, amplitudes of fluctuations)

Place of origin of rain water	Year	pH	Electric conductivity, mS·cm⁻¹	SO_4^{2-}	Ca^{2+}	Mg^{2+}	K^+	Na^+
				mg·l⁻¹				
Control, 30—34 km from the cement plant, W	1984	6.7 6.4—6.9	0.13 0.07—0.18	19 12—24	—	—	—	—
	1985	6.9 6.5—7.3	—	13 9—24	20 2—25	4 3—6	2 1—3	—
	1986	6.3 6.0—6.5	—	11 9—15	45 25—50	5 1—6	3 1—6	4 1—7
	1987	7.0 5.4—7.9	—	26 9—45	23 19—29	7 4—11	4 1—7	3 2—6
	1988	7.0 5.9—7.7	0.15 0.06—0.26	14 9—30	12 8—22	8 1—16	5 1—8	4 2—6
	1989	6.1 5.4—7.0	0.08 0.05—0.17	17 9—39	4 2—5	8 6—11	4 1—7	—
	1990	6.7 6.3—7.0	0.12 0.08—0.15	10 9—12	12 8—17	8 8—9	4 1—7	3 2—4
	1991	7.1 6.6—7.1	0.23 0.16—0.43	24 8—90	30 6—61	3 1—5	3 1—8	3 2—4
0.5—1.0 km from the cement plant, NE	1984	8.0 7.6—8.4	0.52 0.47—0.83	140 55—290	—	—	—	—
	1985	8.2 7.8—8.8	—	117 60—270	46 25—56	8 6—9	24 12—48	—
	1986	7.8 7.5—8.0	—	237 90—375	120 75—200	20 12—30	60 21—103	5 3—9
	1987	7.6 7.1—8.1	—	348 300—420	80 25—164	21 12—26	84 60—112	5 4—6
	1988	8.0 7.7—8.3	0.44 0.27—0.66	244 60—450	61 56—66	14 4—17	85 23—207	5 2—10
	1989	7.8 7.2—8.3	0.56 0.24—1.01	165 75—300	45 30—49	12 11—13	80 18—200	—
	1990	7.7 7.7—7.8	0.68 0.60—0.76	300 240—420	89 77—99	19 17—22	79 61—90	4 4—5
	1991	7.7 7.4—8.1	1.14 0.66—1.92	485 300—675	112 76—147	19 8—34	182 61—492	7 3—10

Results and Discussion

Character of tree growth conditions on sample plots

The main harmful factor for the trees in the vicinity of the cement plant is apparently technological alkaline dust (cement dust), which constitutes 87—91% in the total emission of air pollutants. Products of fuel combustion (CO, SO_2, etc.) are of lesser harm. Data of the cement plant laboratory show that the cement dust from the electric filters contains a complex of substances (40—50% CaO, 12—17% SiO_2, 4—9% K_2O, 4—8% SO_3, 3—5% Al_2O_3, 2—4% MgO, 1—3% Fe_2O_3, etc.) and its pH is

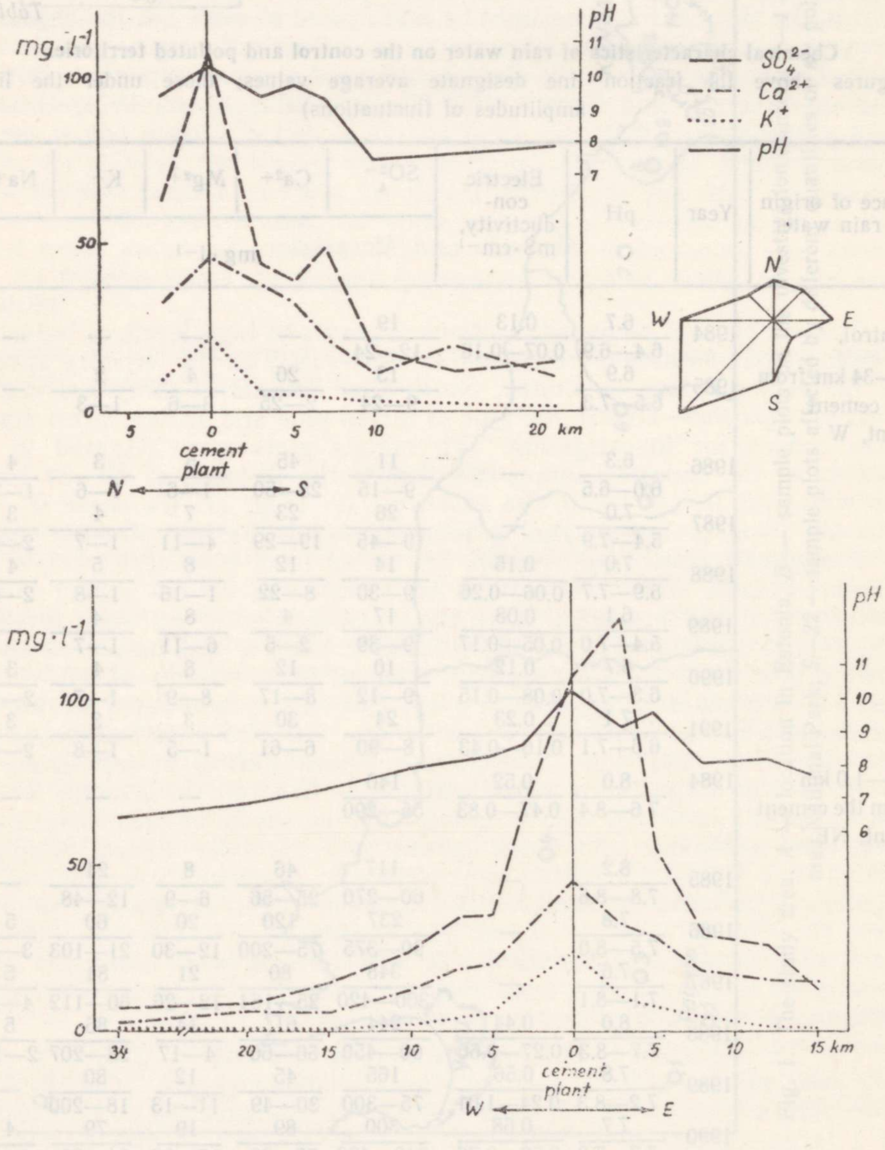

Fig. 2. Some chemical characteristics and pH of snow in February 1987 at different distances to the cement plant.

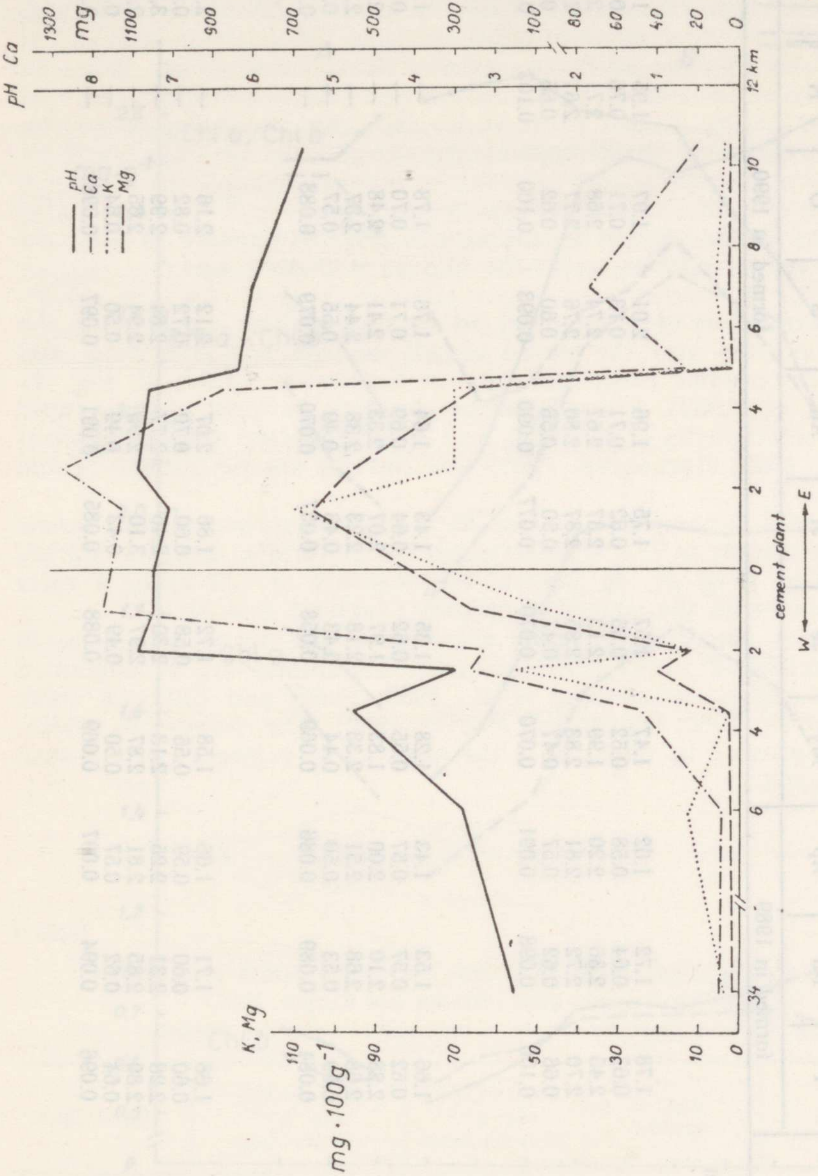

Fig. 3. Some characteristics of soil at different distances from the cement plant in July 1991.

Table 2

Seasonal dynamics of pigments (mg · g^{-1} of dry mass) in one-year-old Norway spruce needles

Sample plots, parameter	1991											1992	
	F	Mr	Ap	My	Je	Jl	Au	S	O	N	D	Ja	F
	formed in 1989			formed in 1990									
Control, 30—34 km from the cement plant, W													
Chl *a*	1.78	1.72	1.62	1.47	1.57	1.75	1.96	2.01	1.97	1.95	1.96	1.96	1.89
Chl *b*	0.67	0.64	0.58	0.52	0.56	0.62	0.71	0.73	0.71	0.76	0.76	0.80	0.77
Chl *a* + Chl *b*	2.45	2.36	2.20	1.99	2.13	2.37	2.67	2.74	2.68	2.71	2.75	2.80	2.66
Chl *a*/Chl *b*	2.70	2.72	2.81	2.83	2.85	2.87	2.80	2.76	2.77	2.61	2.57	2.36	2.45
Carotenoids	0.66	0.62	0.57	0.47	0.47	0.50	0.56	0.60	0.62	0.65	0.64	0.70	0.70
β-Carotene	0.100	0.098	0.091	0.070	0.070	0.077	0.090	0.093	0.100	0.103	0.133	0.129	0.113
0.5—1.0 km from the cement plant, NE													
Chl *a*	1.66	1.53	1.43	1.28	1.35	1.43	1.64	1.76	1.78	—	1.65	1.49	1.43
Chl *b*	0.62	0.57	0.57	0.55	0.62	0.64	0.69	0.71	0.70	—	0.71	0.68	0.66
Chl *a* + Chl *b*	2.28	2.10	2.00	1.83	1.97	2.07	2.33	2.41	2.48	—	2.37	2.18	2.09
Chl *a*/Chl *b*	2.68	2.68	2.51	2.33	2.18	2.23	2.38	2.44	2.57	—	2.31	2.18	2.16
Carotenoids	0.59	0.53	0.50	0.44	0.43	0.43	0.49	0.55	0.57	—	0.57	0.53	0.53
β-Carotene	0.084	0.089	0.086	0.069	0.058	0.057	0.070	0.079	0.088	—	0.086	0.083	0.079
1.5—2.0 km from the cement plant, W													
Chl *a*	1.68	1.71	1.66	1.58	1.72	1.86	2.07	2.12	2.16	—	2.21	1.98	1.91
Chl *b*	0.60	0.60	0.59	0.55	0.58	0.60	0.70	0.72	0.82	—	0.85	0.84	0.80
Chl *a* + Chl *b*	2.28	2.31	2.25	2.13	2.30	2.46	2.77	2.84	2.99	—	3.06	2.82	2.71
Chl *a*/Chl *b*	2.80	2.85	2.81	2.87	2.97	3.10	2.96	2.94	2.65	—	2.66	2.35	2.39
Carotenoids	0.64	0.62	0.57	0.50	0.49	0.43	0.49	0.50	0.64	—	0.68	0.69	0.67
β-Carotene	0.096	0.094	0.097	0.069	0.088	0.085	0.091	0.097	0.098	—	0.133	0.126	0.100

12.7 or even higher. The dust fallout at the distance of about 1—1.5 km from the emission source amounted annually to 1800—2400 g·m^{-2}, depending on the direction and velocity of winds. High dust concentration in the air brings along alkalization of precipitation and changes in its chemical composition (Table 1). The changes in precipitation decrease with the increase in the distance from the emission source (Fig. 2).

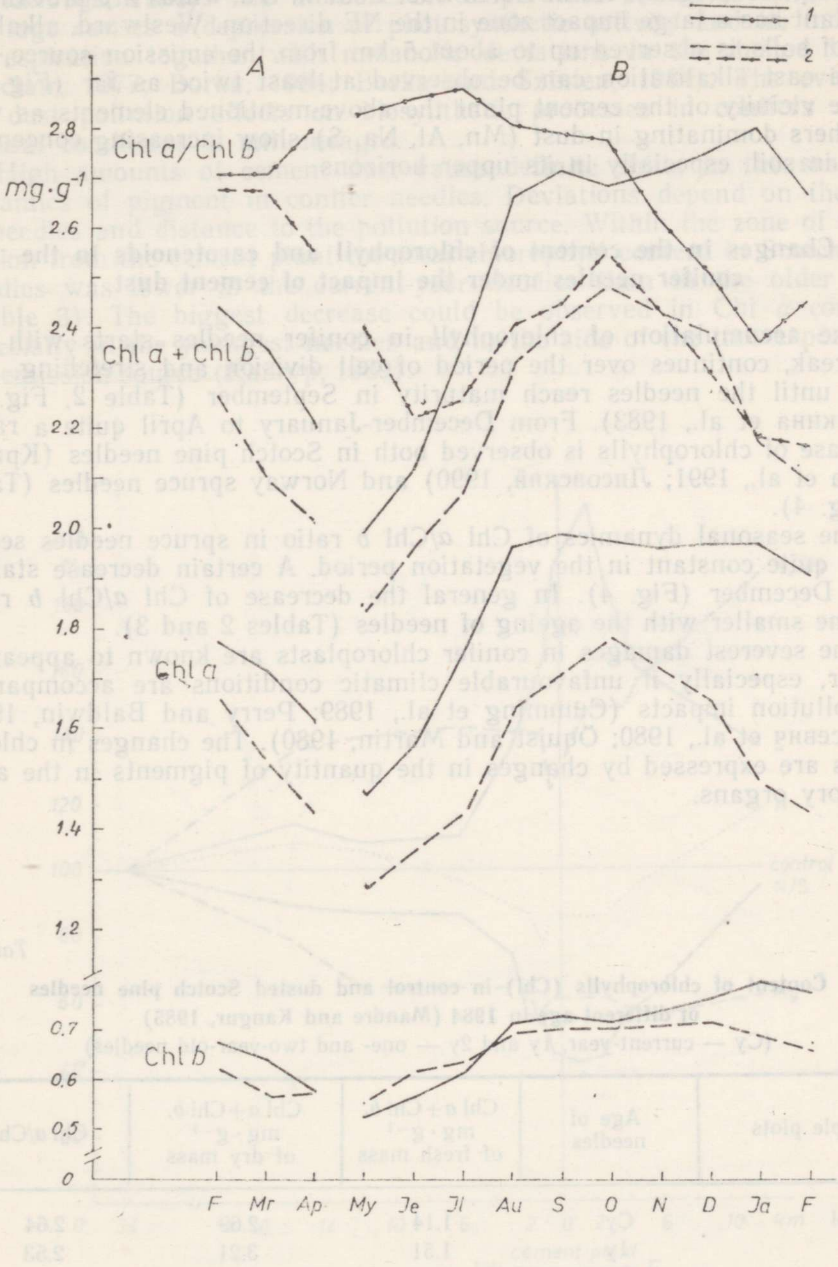

Fig. 4. Impact of alkaline dust on the seasonal dynamics of chlorophylls (mg·g^{-1} of dry mass) in one-year-old Norway spruce needles in 1991—1992. *1* — control; *2* — 0.5—1.0 km from the cement plant; *A* — one-year-old needles formed in 1989; *B* — one-year-old needles formed in 1990.

Soil is a receptor of dry and wet deposits of nongaseous pollutants from the cement plant. Cement dust is a direct cause of strong alkalization of the upper horizons of soil in the vicinity of the cement plant (pH=8.1—8.4). Soil alkalization influences a large number of extremely important biological and chemical processes in the environment.

The major components of the industrial dust in Kunda are Ca, K, and Mg. This accounts for the marked rise in the content of these elements in the soils of that region as compared to the forest soil in the control sample plots (Fig. 3). As in North-East Estonia SW winds are prevailing, the plant has a large impact zone in the NE direction. Westward, alkalization of soils is observed up to about 5 km from the emission source, but to the east alkalization can be observed at least twice as far (Fig. 3). In the vicinity of the cement plant the above-mentioned elements as well as others dominating in dust (Mn, Al, Na, S) show increasing concentrations in soil, especially in its upper horizons.

Changes in the content of chlorophyll and carotenoids in the conifer needles under the impact of cement dust

The accumulation of chlorophyll in conifer needles starts with the budbreak, continues over the period of cell division and stretching, and lasts until the needles reach maturity in September (Table 2, Fig. 4) (Малкина et al., 1983). From December-January to April quite a rapid decrease of chlorophylls is observed both in Scotch pine needles (Кривошеева et al., 1991; Лисовский, 1990) and Norway-spruce needles (Table 2, Fig. 4).

The seasonal dynamics of Chl *a*/Chl *b* ratio in spruce needles seems to be quite constant in the vegetation period. A certain decrease started from December (Fig. 4). In general the decrease of Chl *a*/Chl *b* ratio became smaller with the ageing of needles (Tables 2 and 3).

The severest damages in conifer chloroplasts are known to appear in winter, especially if unfavourable climatic conditions are accompanied by pollution impacts (Cumming et al., 1989; Perry and Baldwin, 1966; Ходасевич et al., 1980; Öquist and Martin, 1980). The changes in chloroplasts are expressed by changes in the quantity of pigments in the assimilatory organs.

Table 3

Content of chlorophylls (Chl) in control and dusted Scotch pine needles of different age in 1984 (Mandre and Kangur, 1985)

(Cy — current-year, 1y and 2y — one- and two-year-old needles)

Sample plots	Age of needles	Chl *a*+Chl *b*, mg · g⁻¹ of fresh mass	Chl *a*+Chl *b*, mg · g⁻¹ of dry mass	Chl *a*/Chl *b*
Control	Cy	1.14	2.69	2.64
	1y	1.51	3.21	2.53
	2y	1.61	3.53	2.32
0.5 km from the cement plant	Cy	0.94	2.20	2.38
	1y	1.29	2.79	2.24
	2y	1.38	3.13	2.25

Cement dust covering the vegetative organs of plants and moisture usually forms a crust on them. This changes light, temperature, and water regimes in the plant tissues. In dusted leaves the absorption of the most active parts of the solar radiation spectrum participating in photosynthetic processes is by 5—14% lower than in unpolluted leaves, while the absorption of the red and infrared regions of the spectrum is by 25—33% higher (Илькун, 1978). As a result, the temperature in the leaves under the dust layer increases approximately 2—4 °C, sometimes even 8—10 °C (Артамонов, 1986). The increase of temperature combined with water shortage causes a depression of photosynthetic activity and an increase in respiration together with metabolic deviations in the dusted leaves (Auclair, 1977; Borka, 1984; Borka and Szinten, 1984). The evidence for dust pollution effects on biosynthetic processes in conifers under natural conditions is still meagre.

High amounts of cement dust cause definite shifts in the seasonal dynamics of pigment in conifer needles. Deviations depend on the age of needles and distance to the pollution source. Within the zone of about 0.5 km from the cement plant the total chlorophyll content in Scotch pine needles was lower in the current-year needles than in the older ones (Table 3). The biggest decrease could be observed in Chl *a* content, especially in the youngest needles and in the side of the tree exposed to the emission source (Кангур, 1989).

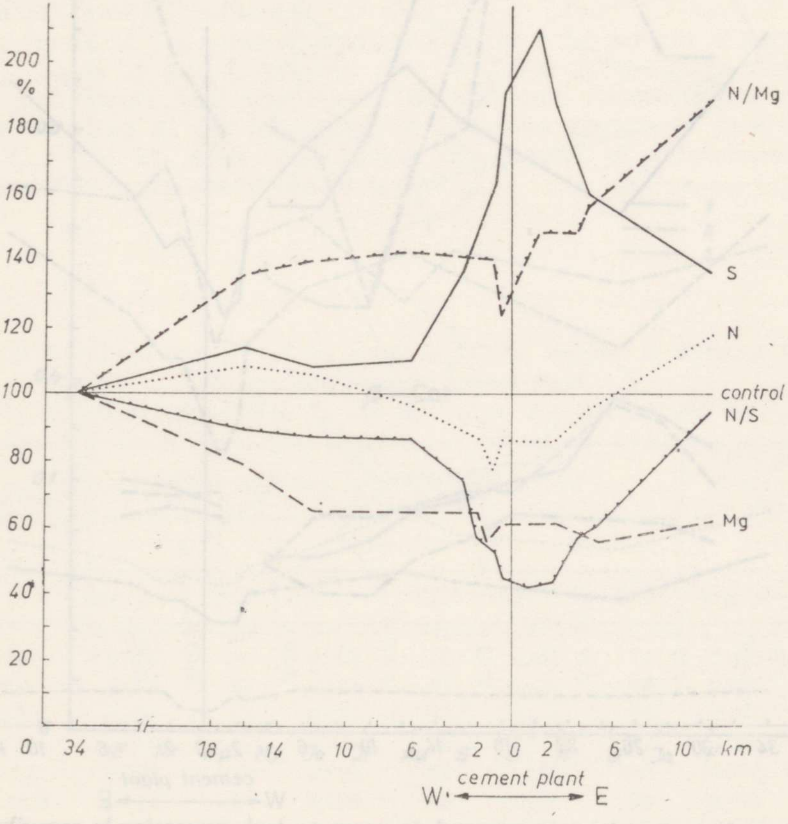

Fig. 5. The concentration of some chemical elements in one-year-old Norway spruce needles at different distances from the cement plant in July 1991.

The same was observed in the needles of Norway spruce: Chl *a* was susceptible to dust while Chl *b* seemed to be rather tolerant (Fig. 4). The relative tolerance of Chl *b* to dust pollution may be explained by the fact that Chl *b* is synthesized from Chl *a* molecules in enzymatic dark processes (Шлык et al., 1975). A rapid decrease of Chl *a*/Chl *b* ratio in spruce needles occurred under the impact of great dust pollution within the distance of 0.5 km from the cement plant, with differences from the controls reaching 21% (Table 2; Fig. 4). The sensitivity of Chl *a*/Chl *b* ratio to cement dust pollution has been shown by Kangur and Ploompuu (1991) in *Betula pendula* and *B. pubescens* as well. On the contrary, the reduced pollution level that occurs farther than 1.5—2.0 km away from the cement plant seems to stimulate chlorophyll biosynthesis and increase the level of Chl *a* and Chl *a*/Chl *b* ratio (Table 2, Fig. 5).

The chlorophyll decrease in Norway spruce and Scotch pine needles under the impact of high technogenic loads in the vicinity of the cement plant may be related to the effect of several mediating factors. One is probably the deficiency of nitrogen and magnesium in tissues (Fig. 5). Though the concentration of magnesium in the soil horizon of feeding roots (at the depth of 30 cm) is relatively high (Fig. 3), the alkalization of soil at that depth may hinder its uptake by plants (Берзиня, 1985). Figs. 5 and 6 show that the courses of changes in the concentration of chlorophyll and N/Mg ratio in Norway spruce needles plotted against

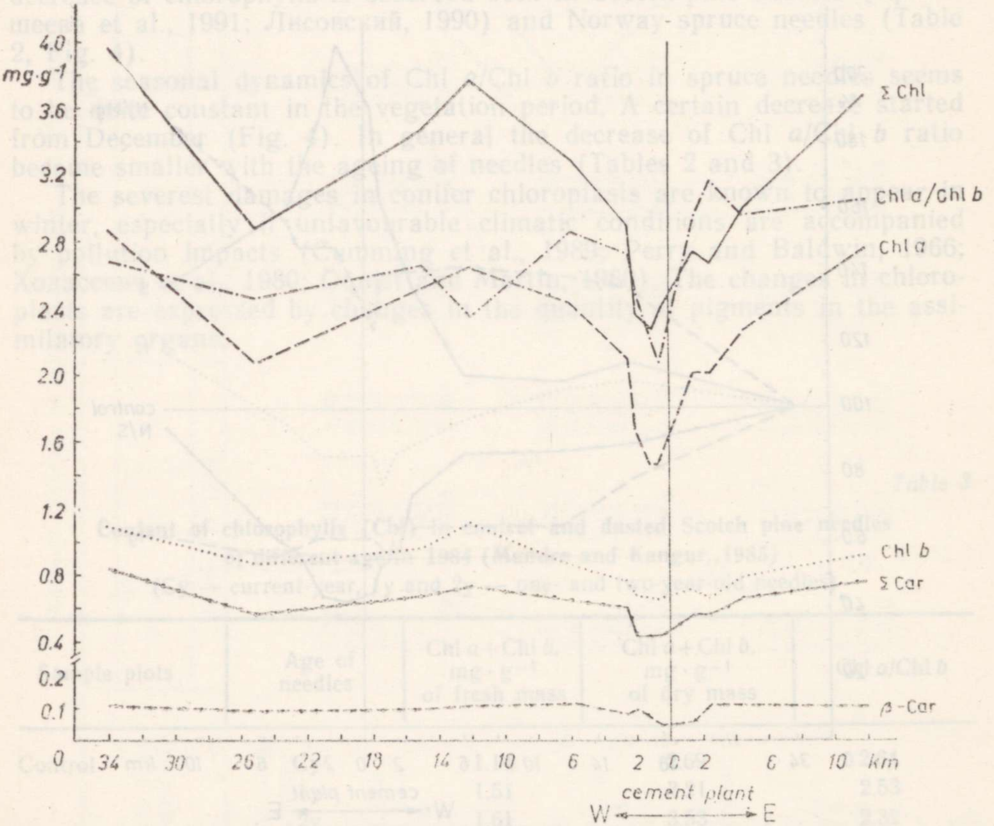

Fig. 6. The concentration of pigments in one-year-old Norway spruce needles at different distances from the cement plant in July 1991.

the distance to pollution source are very similar. Besides, the high concentration of sulphuric compounds observed in needles near the pollution source seems to influence chlorophyll metabolism. It was shown in our recent work (Mandre, 1989) that the influence of cement dust pollution brings about deviations in sulphur metabolism and increases the content of SH-groups and SO_4 in conifer needles. Long exposure of enzyme systems such as chlorophyllase to pollutants containing sulphur has been shown to result in chlorophyll destruction (Malhrota and Hocking, 1976).

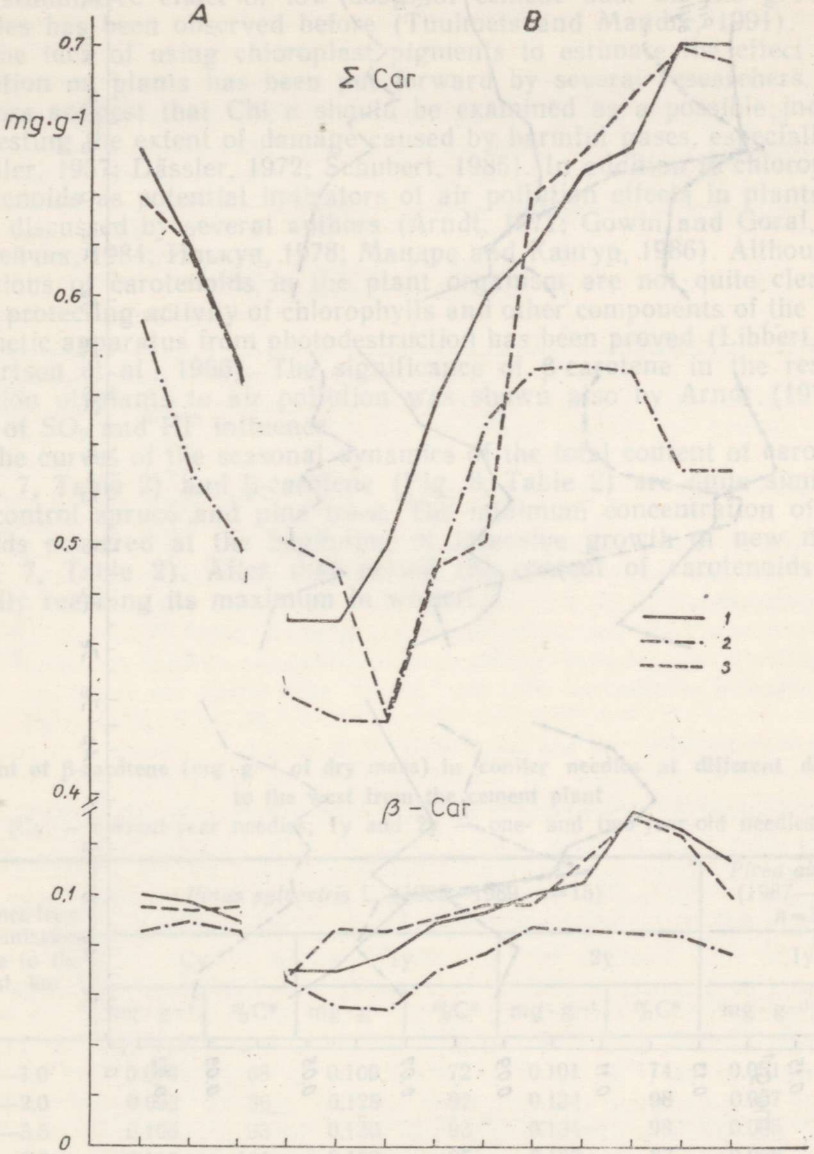

Fig. 7. Influence of calcareous dust on seasonal dynamics of total content of carotenoids and β-carotene in one-year-old Norway spruce needles in 1991—1992.
1 — control; *2* — 0.5—1.0 km and *3* — 1.5—2.0 km from the cement plant; *A* — one-year-old needles formed in 1989; *B* — one-year-old needles formed in 1990.

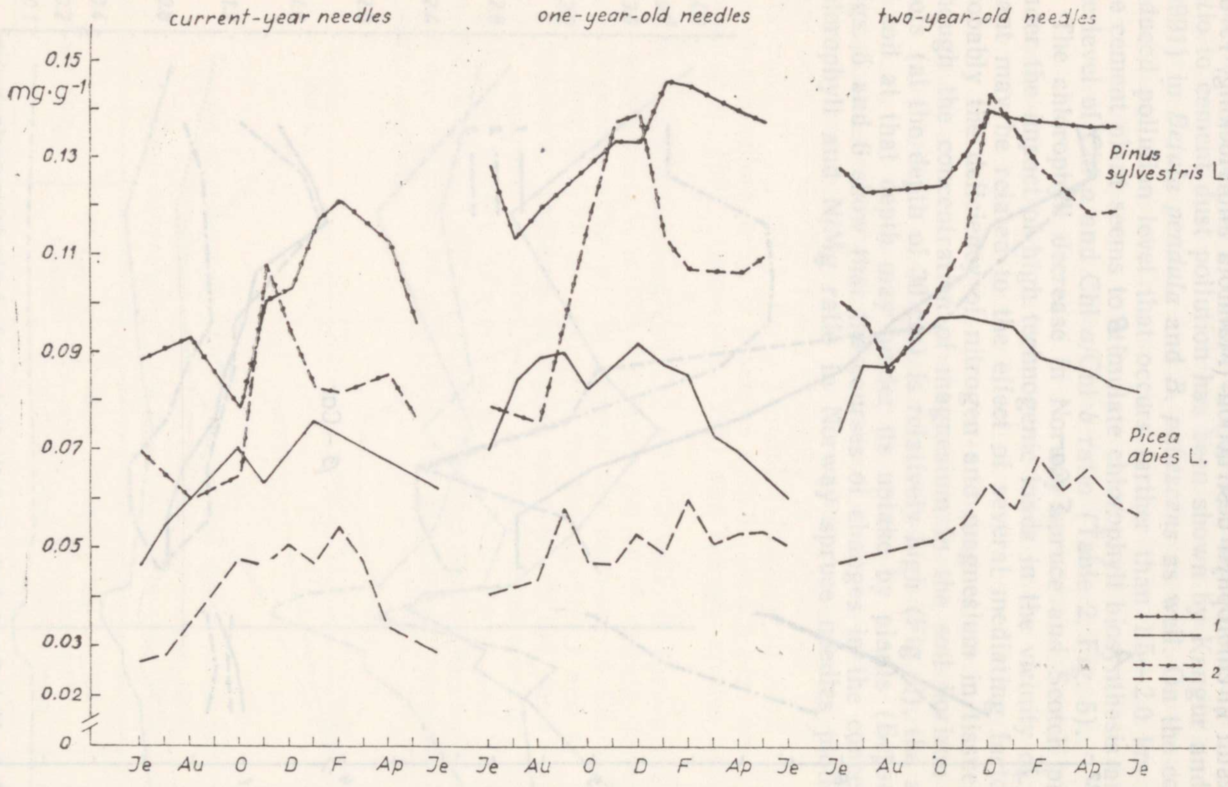

Fig. 8. Differences in the seasonal dynamics of β-carotene in Norway spruce and Scotch pine needles of different ages in the vicinity of the cement plant and in an unpolluted territory.

This suggestion is confirmed by Anderson and Duggan (1977), who found the light modulation of chloroplast enzyme activities to be inhibited by sulphite as well as by exposure to SO_2. It is possible that changes in the chloroplast function are brought about by light deficiency and disturbed gas exchange in needles under the cement crust on needles (Илькун, 1978). Farther than 2 km from the emission source, where dust pollution is not heavy, the increase in chlorophyll content in needles may be interpreted as a compensation reaction typical of plants growing in shade (Kramer and Kozlowski, 1979; Troeng and Linder, 1982) or as a favourable effect of the increase in N/Mg ratio and ratios of other elements. The stimulative effect of low doses of cement dust on the growth of needles has been observed before (Tuulmets and Mandre, 1991).

The idea of using chloroplast pigments to estimate the effect of air pollution on plants has been put forward by several researchers. Some authors suggest that Chl *a* should be examined as a possible indicator for testing the extent of damage caused by harmful gases, especially SO_2 (Müller, 1957; Dässler, 1972; Schubert, 1985). In addition to chlorophylls, carotenoids as potential indicators of air pollution effects in plants have been discussed by several authors (Arndt, 1971; Gowin and Goral, 1977; Сергейчик, 1984; Илькун, 1978; Мандре and Кангур, 1986). Although the functions of carotenoids in the plant organism are not quite clear yet, their protecting activity of chlorophylls and other components of the photosynthetic apparatus from photodestruction has been proved (Libbert, 1974; Robertson et al., 1966). The significance of β-carotene in the response reaction of plants to air pollution was shown also by Arndt (1971) in case of SO_2 and HF influence.

The curves of the seasonal dynamics of the total content of carotenoid (Fig. 7, Table 2) and β-carotene (Fig. 8, Table 2) are quite similar in the control spruce and pine trees. The minimum concentration of carotenoids occurred at the beginning of intensive growth of new needles (Fig. 7, Table 2). After that period the content of carotenoids grew rapidly reaching its maximum in winter.

Table 4

Content of β-carotene ($mg \cdot g^{-1}$ of dry mass) in conifer needles at different distances to the west from the cement plant

(Cy — current-year needles; 1y and 2y — one- and two-year-old needles)

Distance from the emission source to the west, km	*Pinus sylvestris* L. (1985—1989, $n=15$)						*Picea abies* L. (1987—1991, $n=5$)	
	Cy		1y		2y		1y	
	$mg \cdot g^{-1}$	%C*	$mg \cdot g^{-1}$	%C*	$mg \cdot g^{-1}$	%C*	$mg \cdot g^{-1}$	%C*
0.5—1.0	0.078	68	0.100	72	0.101	74	0.051	65
1.5—2.0	0.098	86	0.128	92	0.134	98	0.057	72
3.0—3.5	0.106	93	0.130	93	0.134	98	0.065	82
5.0—6.0	0.115	101	0.132	95	0.133	87	0.066	84
9.0—10.0	0.120	105	0.128	89	0.140	102	0.075	94
14.0—16.0	0.113	99	0.129	93	0.127	93	0.085	108
30.0—34.0 (control)	0.114	100	0.139	100	0.137	100	0.079	100

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* %C — % of control

Cement dust caused a drop in the total carotenoid concentration (Figs. 7 and 8; Table 2). Though the data presented in Table 4 and Fig. 6 reflect the content of carotenoids in spruce and pine needles in different seasons, its dependence on the distance to the cement plant is evident. Data in Table 4 show that spruce was more sensitive to dust pollution than pine. The results presented demonstrate that the concentration of β-carotene observed in trees of the control site is achieved at the distance of about 10 km from the cement plant in spruce needles, versus 2 km in the case of pine (Table 4).

Table 5

Content of β-carotene (mg · g⁻¹ of dry mass) in Norway spruce (mean content in 1987—1988) and Scotch pine (mean content in 1984—1985) needles of different ages

(Cy — current-year needles; 1y, 2y, 3y, 4y, 5y, 6y — one- to six-year-old needles)

Species	Age of needles	Control, mg · g⁻¹	0.5 km from the cement plant	
			mg · g⁻¹	% of control
Picea abies L.	Cy	0.061	0.040	66
	1y	0.074	0.049	66
	2y	0.089	0.058	65
	3y	0.090	0.062	69
	4y	0.092	0.065	71
	5y	0.086	0.068	79
	6y	0.084	—	—
Pinus sylvestris L.	Cy	0.102	0.081	79
	1y	0.134	0.108	82
	2y	0.133	0.116	87

The content of β-carotene in conifers was found to be lower in current-year needles than in older ones (Table 5). The highest concentration of that pigment was estimated for 3—4-year-old spruce and the oldest survived pine needles. The curve of the seasonal dynamics of β-carotene under a high pollution level was lower than that of the needles of the control trees. The pine needles of the control sample site achieve the winter maximum of β-carotene content in January and February. In the younger pine needles at the distance of 0.5 km from the cement plant the winter maximum seemed to arrive rapidly and about one month earlier than in the control pines (Fig. 8). This permits us to suggest that the intensive increase of β-carotene concentration in pine needles in winter serves to protect the photosynthetic apparatus from the unfavourable conditions such as low temperature and air pollution. In spruce needles the β-carotene content was low in the vicinity of the cement plant throughout the year.

Conclusion

The present investigation showed that the response reactions of the pigment complex of pine and spruce needles to alkaline dust pollution depend on season, age of needles, and the level of dust pollution along the deposition gradient. The pollution injuries of trees in the vicinity of the cement plant are mostly expressed as a decline of Chl *a* content and Chl *a*/Chl *b* ratio. The deficiency of light and N and Mg in needles under the cement crust is one possible reason of reduced Chl *a* biosynthesis. Relative tolerance of Chl *b* to dust effect was observed.

The content of carotenoids in needles is also depressed under dust pollution. But the abrupt increase in the content of β-carotene earlier than the control trees reach their winter maximum allows us to suggest its significance in the protective reaction in the affected Scotch pine needles. No such reaction was observed in the needles of Norway spruce.

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