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IMPACT OF AIR POLLUTION EMITTED FROM THE CEMENT INDUSTRY ON FOREST BIOPRODUCTION

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Research has shown that alkaline emissions of the Kunda Cement Plant in NE Estonia cause changes in the physiological-biochemical conditions of conifers reducing their bioproduction and vitality. The dependence of radial increment of 75-85-year old Pinus sylvestris *L. and* Picea abies *L. on high concentrations of K and Ca in the growth environment (soil, precipitation, air) and the level of pollution load is discussed. Among the pollutants emitted by the Kunda Cement Plant, of which dust (pH = 12.3-12.6) has accounted for 87-96 % in recent years, alkaline components predominate. These have an important effect on the reaction (pH = 7.2-7.9) and chemical composition of precipitation.*

A clear fall can be observed in the radial increment of pine and spruce on observation sites at a distance of 2-3 km to the west and up to 5 km to the east form the cement plant where the emission load is especially big (1000-2400 g m^{-2} yr^{-1}). The effect of alkaline dust pollution on conifers growing farther away from the cement plant (5-15 km to the west and over 10 km to the east, 100-300 g m^{-2} yr^{-1}) is insignificant.

Introduction

Different species of woody plants respond differently to air pollution. In case of the plants of the same species, the response depends on the concentration of pollutants, soil, and weather conditions, the location of the plant on the relief and within the association as well as on the development stage of the plant. The effect of pollutants on Scotch pine and Norway spruce, which are considered sensitive towards pollution, is reflected in their metabolism, as a consequence of which also their production changes [1, 2].

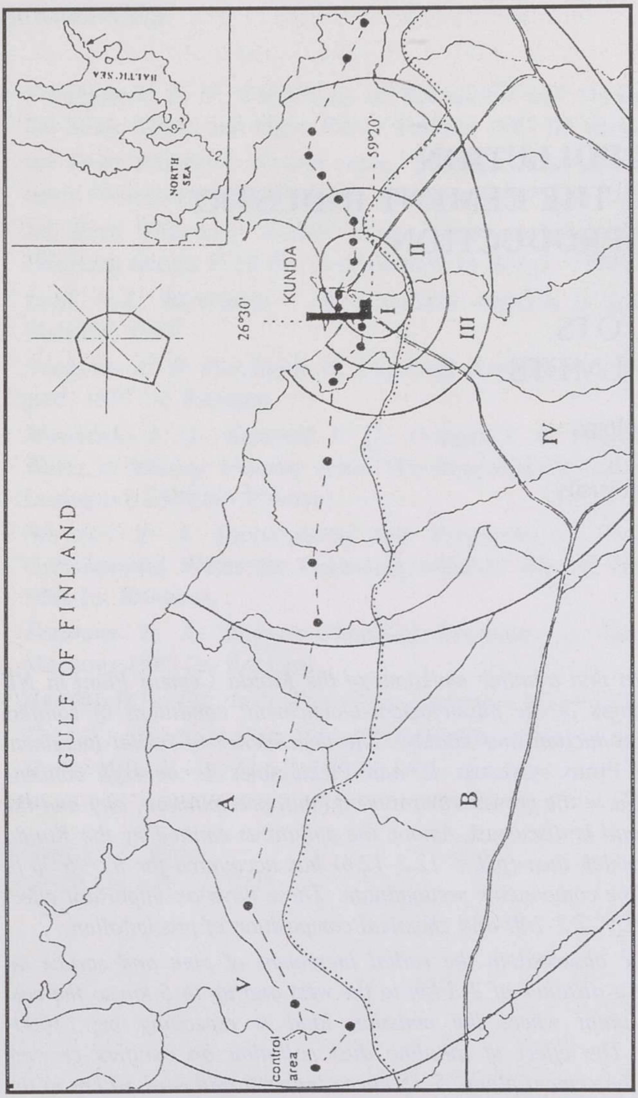

Fig. 1. Influence zones of the KundaCement Plant and the studied transect with observation sites [11]:
I - strongly influenced area(up to 2 km west and 3 km east from the plant, pollution load 1800-2700 g m^{-2} per year);
II - significantly influenced area(2-3 km west and 3-5 km east, 1000-1800 g m^{-2} per year);
III - moderately influenced area(3-5 km west and 5-10 km east, 300-1000 g m^{-2} per year);
IV - weakly influenced area(5-15 km west and over 10 km east, 100-300 g m^{-2} per year);
V - control area(30-38 km west). *A* - North-Estonian Coastal Plain; *B* - Northeast Estonian Plateau

Radial increment of older pine stands near Moscow in the early 20th century was bigger than that of the stands of same age in the early 1960s [3]. Changes in increment have been observed also in conifer stands in industrial regions of Central and Eastern Europe [4-6]. Trees of Kraft classes II and III with diameters close to average were more resistant to human impact. In Estonia, deviations in conifer increment are known to occur in the city of Tallinn [7, 8] and in the industrial region of NE Estonia [9-14]. Numerous authors stress the dependence of increment on pollution load and chemical composition of pollutants [15-18].

In pollution research attention has been focused mostly to elucidating the effect of complexes with acidic reaction. The effect of dust pollution on trees has been paid relatively little attention to although dust pollution makes up over 10 % of the total air pollution in the world [19]. Its proportion is expected to rise even further as a result of intensified transportation, open-pit mining, and the metal industry [20]. Enterprises producing building materials are an important source of dust pollution. The dust emitted from a cement plant is predominantly alkaline and, according to different authors, its effect on plants may be either favourable or unfavourable.

Raymond and Nussbaum [21] state that the influence of cement dust on forest trees is negligible whereas Manning [22] is of the opinion that it retards increment significantly. Brandt and Rhoades [23], estimating the effect of a lime quarry and plant on forest stands, found important changes in the species composition of young reproduction, reduced increment and symptoms of necrosis on leaves. Cement dust affects adversely the increment of oak stands, especially in years with little precipitation [24].

Applying comparative analysis, the present study discusses deviations in the radial increment of Scotch pine, *Pinus sylvestris* L., and Norway spruce, *Picea abies* (L.) Karst., due to a high load of pollutants emitted by a cement plant and the ensuing changes in the environment. Attention was focused on the analysis of the growth and development parameters of conifers based on increment material, associating them with environmental parameters, particularly with pollution load but also with data on the composition of precipitation and soil.

Material and Methods

The research was carried out on a transect in the region of the Kunda Cement Plant (established in 1871) in NE Estonia (Fig. 1). Differences in the increment of conifers in the influence zone of the dust pollution emitted by the plant and in a relatively unpolluted area were estimated. The selected transect was a 50 km long land strip in the coastal zone, which extended 38 km to the west and 12 km to the east from the plant.

In selecting forest observation sites, attention was paid mainly to comparability of stands. Similarity of climatic and edaphic conditions and forest survey indicators was an important principle. The selected stands were close as to their site type (*Myrtillus*-type pine or spruce stands), quality class (II), composition of trees, age (75-85-year-old), and density (0.7-0.8) with no traces of sanitation felling. This made it possible to eliminate the effect of numerous external (climate, phytocoenotic, anthropogenic, etc.) and internal (biological age, genetic properties, etc.) factors affecting radial increment in addition to pollution load.

For estimating anthropogenic changes in industrial landscape, statistical relationships between the width of the annual rings and the pollution load and indicators of precipitation and soil composition were found. To get objective information, at each site increment cores were taken from 15-20 dominant or co-dominant trees at the northern and southern sides of the trees at the height of 1.3 m with an increment borer. The widths of tree rings on cores were measured with a microscope. To eliminate the effect of local random factors affecting individual trees average parameters of sample plots were used. These were grouped by sample plots and influence zones of the cement plant. Using the measurement data, graphs of radial increment were drawn.

For correlation and regression analyses and for finding statistical differences (*t*-test) the programs STATGRAPHICS 5.0 and EXCEL 5.0 were used.

Changes in the Growth Environment of Stands

The total amount of dust emitted by the Kunda Cement Plant varies depending on the condition of equipment and production intensity. According to the information provided by the plant, the maximum emission, 98,900 tonnes, occurred in 1991. In recent decades, dust has made up 87-96 % of the summary emission. The amount of various exhaust gases (SO_2, NO_x, CO, etc.) has been smaller. Analyses made in the laboratory of the plant show that the dust contains 42.5 % CaO, 13.5 % SiO_3, 7.8 % K_2O, 7.5 % SO_3, 3.6 % Al_2O_3, 2.8 % Fe_2O_3, 2.7 % MgO, 0.13 % Na_2O, 0.04 % TiO_2 and 0.03 % MnO [12]. The amounts of Cl, Ba, and Sr are also relatively big. These are followed by Zn, Pb, Cr, Cu, and other elements. The large amounts of cement dust emitted by the plant have caused notable alkalisation of precipitation in the town of Kunda and in its vicinity [25-28].

Transect studies carried out in 1993 showed that the pH value in Kunda was 7.9, at a distance of 10-12 km to the east 7.2 and to the west 7.3. These values are notably higher than the values suggested by Austrian scientist Smidt [29] as normal for precipitation (pH = 5.11-6.10) and than those of our control area (pH = 6.1-6.7). The high concentration of dominating elements (Ca, K, etc.) in the dust has brought about also a rise in the pH value of snowmelt, which is usually over 10.0 in the town of Kunda (control 6.8-7.0) [28].

Dust from the cement industry has had a serious impact on soil towards alkalisation [30, 31]. In the forest the pH value of the upper horizons of weakly podzolised temporarily overmoist sandy soils has risen by up to 4.5 units [32, 33]. The technogenic influence is the strongest in the litter layer of forest soil and it decreases towards deeper layers being in areas with a higher pollution load observable up to the depth of 70 cm. As compared to the control area the Ca and Mg content in the upper horizons of soil is 15 times higher, that of K 2-4 times, S up to 3 times and Al 5 times higher [33]. The content of several microelements is also elevated. However, the content of total nitrogen and carbon has decreased. The carbon-nitrogen ratio (C/N) is likewise smaller, which indicates to changes in the biological efficiency in the soil [30]. In the horizontal direction a strong influence of emissions can be observed in the leeward direction from the prevailing winds (to the east and north-east) up to 5 km from the plant (in the windward direction up to 2 km) while a weak influence can be observed at a distance up to 15 km.

Results and Discussion

Our results indicated a strong effect of the pollution complex emitted from the cement plant on radial increment of conifers. Inhibited radial increment was clearly observed in pines growing in sample plots 2-3 km west and 5 km east from the plant (influence zones I and II). In these zones the amount of emissions is especially high (1000-2400 g m^{-2} yr^{-1}) (Figures 1 and 2). Some reduction in radial increment could be observed also in zone III (6 km west from the plant).

Table 1. **Correlations of Radial Increments and Parameters of the Growth Environment and their Significance in the Observation Sites on the Transect**

Parameter	Radial increment			
	Scotch pine		Norway spruce	
	r	*p*	*r*	*p*
Pollution 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
Groundwater				
pH	–	–	-0.76	<0.01
Ca	–	–	-0.91	<0.001
K	–	–	-0.83	<0.001
S	–	–	-0.76	<0.01
Meltwater				
pH	–	–	-0.70	<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				
pH	-0.8	<0.05	-0.83	<0.05

Note: – no significant correlation was observed.

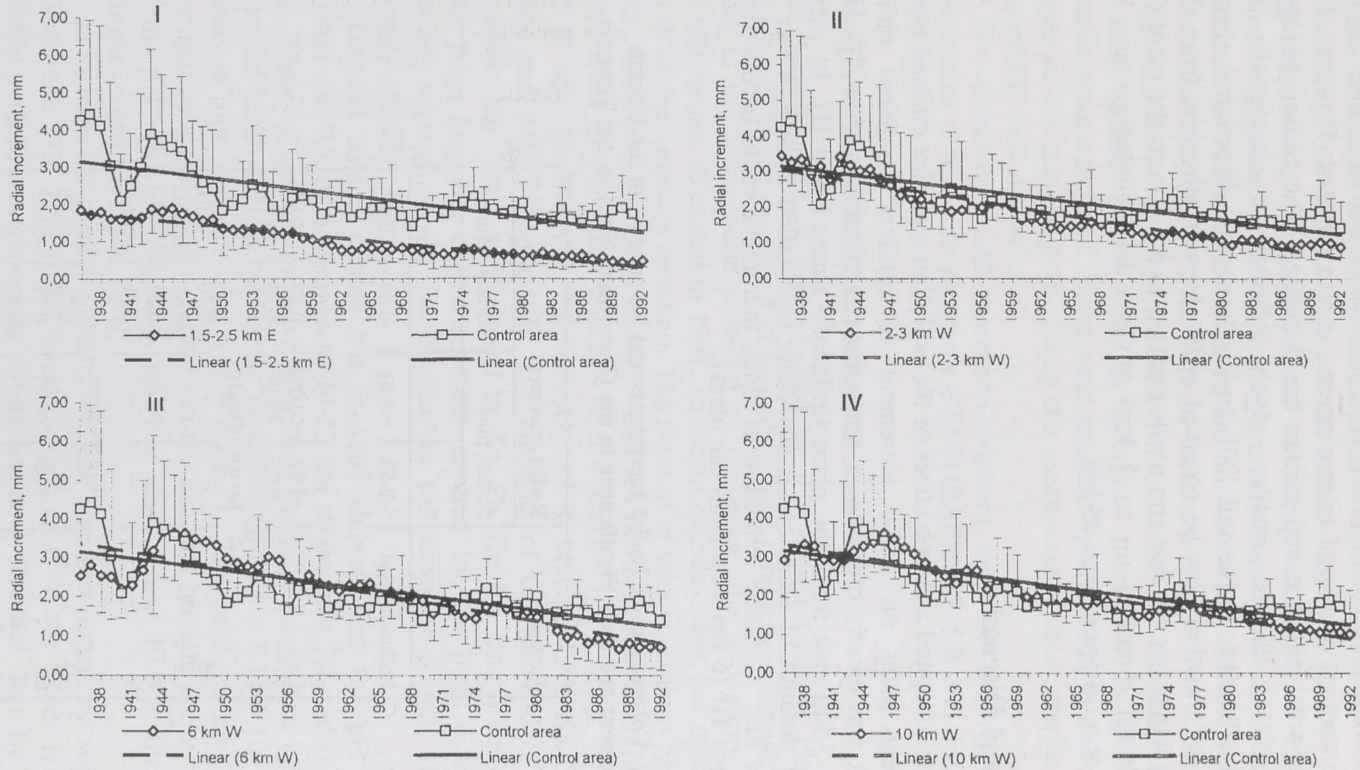

Fig. 2. Radial increments of Scotch pine (mean ±SD, n = 30-40) in areas strongly (I), significantly (II), moderately (III) and weakly (IV) affected by the cement plant and in the control area

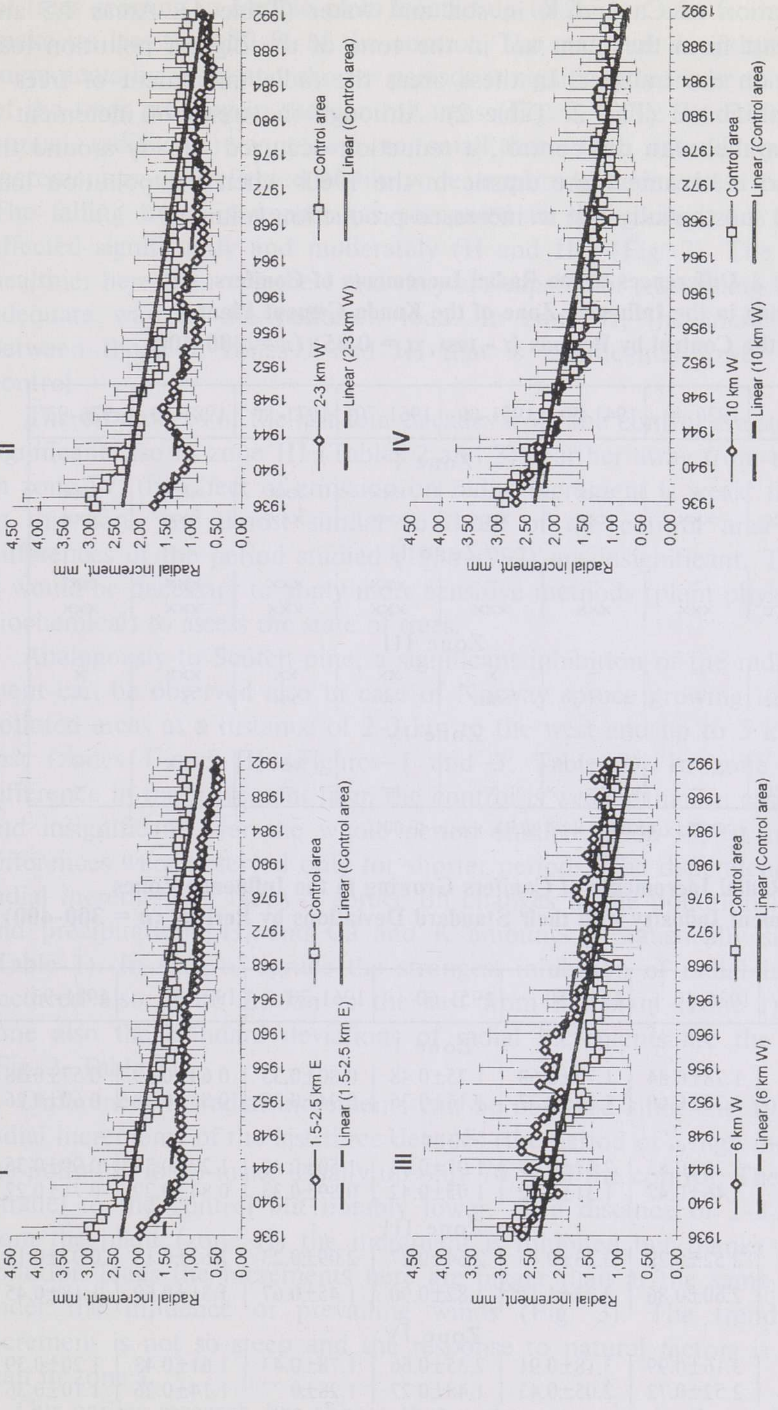

Fig. 3. Radial increments of Norway spruce (mean ±SD, n = 30-40) in areas strongly (I), significantly (II), moderately (III) and weakly (IV) affected by the cement plant and in the control area

Radial increment was correlated to the pollution load and the concentration of Ca and K in soil and water (Table 1). Areas 1.5 and 2.5 km east from the plant are in the zone of the highest pollution load (zone I) on the transect. In these areas the radial increment of trees is strongly inhibited (Fig. 2; Table 2). Although the trend of increment is almost parallel with the control, a reduction occurred already around the 1930s and it became more drastic in the 1960s when the pollution load increased substantially due to increased production volumes.

Table 2. **Differences in the Radial Increments of Conifers Growing in the Influence Zone of the Kunda Cement Plant from the Control by Periods (t - test, $\alpha = 0.05$) (n = 300-400)**

	1936-40	1941-50	1951-60	1961-70	1971-80	1981-93	1936-93
Zone I							
Pine	×	×××	×××	×××	×××	×××	×××
Spruce	×××	×××	×××	×××	×××	×××	×××
Zone II							
Pine	–	–	–	×××	×××	×××	××
Spruce	×××	×××	×××	×××	×××	×××	×××
Zone III							
Pine	–	–	×	××	××	×××	×
Spruce	–	–	×××	×	××	×	–
Zone IV							
Pine	–	–	–	–	××	×××	–
Spruce	–	–	–	–	–	–	–

Note: – $p > 0.05$; × $p \leq 0.05$; ×× $p \leq 0.01$; ××× $p \leq 0.001$.

Table 3. **Radial Increments of Conifers Growing in the Influence Zones of the Cement Industry with their Standard Deviations by Periods (n = 300-400)**

	1936-40	1941-50	1951-60	1961-70	1971-80	1981-93
Zone I						
Pine	1.78±0.84	1.72±0.68	1.25±0.48	0.80±0.35	0.69±0.33	0.57±0.28
Spruce	1.72±0.60	1.21±0.37	1.16±0.36	0.94±0.39	0.85±0.35	0.60±0.26
Zone II						
Pine	3.20±0.83	2.77±0.87	1.97±0.53	1.50±0.40	1.22±0.37	0.99±0.35
Spruce	1.46±0.47	1.31±0.42	1.05±0.42	0.89±0.33	0.84±0.29	0.71±0.27
Zone III						
Pine	2.52±0.22	3.23±0.45	2.64±0.27	2.09±0.23	1.63±0.15	0.97±0.18
Spruce	2.60±0.86	2,23±1.15	1.82±0.90	1.45±0.67	1.31±0.69	1.18±0.45
Zone IV						
Pine	3.16±0.99	3.18±0.91	2.35±0.66	1.78±0.43	1.61±0.43	1.20±0.39
Spruce	2.52±0.72	2.05±0.43	1.48±0.27	1.28±0.[illegible]	1.14±0.26	1.10±0.36
Control						
Pine	3.58±2.08	3.00±1.52	2.09±0.92	1.77±0.63	1.90±0.45	1.63±0.43
Spruce	2.71±0.93	2.13±0.77	1.53±0.64	1.30±0.51	1.15±0.62	1.10±0.64

Since the end of the 1950s to the present, the average radial increments of trees growing in sample plots located up to 2.5 km east from the plant make up less than 50 % of the control. The standard deviation of radial increments by years and shorter periods is significantly lower than in case of the trees growing in the control areas (Fig. 2, Table 3). Differences in annual radial increments are so small here that natural cyclicity of increment is not reflected within wide amplitude under these conditions. The falling trend is steeper (as compared to the control) in the zones affected significantly and moderately (II and III) (Fig. 2). The trees are healthier here than in zone I and they are capable of responding in a more adequate way to the pollution load. In zone II, the increments are between those of zones I and III that is significantly lower than the control.

The differences of the last four decades from the control are statistically significant also in zone III (Tables 2 and 3). Farther away from the plant, in zone IV, the effect of emission on radial increment is weak: the trends in this zone are almost similar to those of the control area and the differences of the period studied (1936-1992) are insignificant. Therefore, it would be necessary to apply more sensitive methods (plant physiological, biochemical) to assess the state of trees.

Analogously to Scotch pine, a significant inhibition of the radial increment can be observed also in case of Norway spruce growing in strongly polluted areas at a distance of 2-3 km to the west and up to 5 km to the east (zones I and II) (Figures 1 and 3; Table 2). In zone III, the difference in the increment from the control is weaker than in case of pine and insignificant over the whole period studied (1936-1993); significant differences were observed only for shorter periods. The dependence of the radial increment of Norway spruce on changes in the pollution load, soil and precipitation pH, and Ca and K amounts is statistically significant (Table 1). In case of spruce the strongest inhibition of radial increment occurred also up to 2.5 km to the east from the plant (zone I), in this zone also the standard deviations of radial increments are the smallest (Fig. 3, Table 3).

Differences in radial increments can be observed since the 1930s. The radial increments of the last three decades (the period of a high increase in the pollution load) make usually up only 70 % of the control. The trend is parallel to the control but notably lower. At a distance of 2-3 km west from the plant (zone II) the increment is inhibited but thanks to lower pollution loads the increments here are bigger than at the same distance under the influence of prevailing winds (Fig. 3). The trend of the increment is not so steep and the response to natural factors is stronger than in zone I.

Our earlier research has shown that a slow increase in the technogenic stress with small variations during the earlier period of cement production and its drastic rise in the 1960s are reflected in the radial increment of pine also in relatively drier sites [34]. In such sites inhibited radial increment can be observed in the close neighbourhood of the pollution source (at a distance of 0.5 km) in case of middle-aged Scotch pine already in the first decade of the 20th century, trees of the same age growing farther away from the cement plant were not yet damaged at that time. Under such conditions, a significant inhibition of radial increment at a distance of up to 3 km from the plant can be observed since the early 1930s; a correlation with the increasing emission occurs. The response of middle-aged trees to the same pollution loads is stronger than that of older trees [34]. The strong pollution stress of the cement industry is thought to suppress extensive response of trees to several natural factors. Such a possibility has been suggested by several authors [24].

Conclusions

High sensitivity of Scotch pine and Norway spruce to pollutants emitted by the cement plant is reflected in changes in their radial increment. A strong correlation was observed with high concentrations of K and Ca in the environment (air, soil, and groundwater).

Although cement plant emissions may have a positive effect on the length growth of needles and shoots when the concentrations are low [11], our findings indicate a clear reduction in the radial increment of conifers and its correlation with the pollution load in the area strongly affected by the cement plant (pollution load 1000-2700 g m^{-2} yr^{-1}).

In areas moderately affected by cement, production (300-1000 g m^{-2} yr^{-1}) significant differences in the radial increment from the control were observed mainly in case of Scotch pine. In remoter areas within the influence zone of the cement plant, the weak concentrations of pollutants (100-300 g m^{-2} yr^{-1}) do not exert so strong stress on conifers that their increment would change significantly.

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