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# *Pinus sylvestris* needle surface characteristics in alkalisied environment

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The objective of the current research was to estimate the effects of a cement factory on needles of *Pinus sylvestris* over a period of 3 years. Four sites within a 10 km distance from the factory were chosen. Comparison of the needle surface area covered by structural wax (SW) and assessment of wettability (*i.e.* contact angles, CA) in all cases has revealed a reliably ( $p < 0.05$ ) worst condition of needles sampled from a site closest to the factory. Wax and dust amounts were highest for needles taken from that site. CA and SW of one-year-old needles had a higher correlation with the concentrations of air pollutants and distances of pine sampling sites than had the current-year needles; opposite data have been obtained for the amounts of wax or dust.

**Key words:** conifers, wettability, epicuticular wax

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## INTRODUCTION

Evaluation of the effects of dust pollution on vegetation has never received the same level of attention as that given to phytotoxic pollutants such as SO<sub>2</sub>, NO<sub>2</sub>, and O<sub>3</sub>. It has been shown that even quite low concentrations of lime/cement dust may cause effects which ranged from blocked stomata and leaf injury symptoms to disturbance of mineral nutrition and overall reduction in growth [1–6]. In addition, the dust has also been identified as a factor damaging the surface waxes of the needles [7–8]. The “Akmencementas” cement factory has been one of the heaviest polluters in Lithuania. Emissions from the factory in 1989–1991 accounted for 60–70 thou. t of pollutants annually, and in the last decade this amount has decreased nearly ten times. In the area affected by the cement factory, chemical properties of air and soil were examined and visual evaluation of forest stands was performed [9]. Evaluation of the needle surface properties near the other local pollution sources in Lithuania has revealed significant structural surface damage in the needles sampled from sites where air pollutants exceeded the critical level [6, 8, 10, 11]. The present study is aimed at evaluation of the cement factory effects on surface characteristics of the needles of *Pinus sylvestris* growing on the sites with different level of pollutants and located at different distances from the source of pollution.

## MATERIALS AND METHODS

The area affected by the cement factory was investigated. During the study period (1994–1996) total annual emissions reached 18.1–5.8 thou. t yr.<sup>-1</sup> including 3.0–1.9 thou. t yr.<sup>-1</sup> dust (data of the Environment Ministry of Lithuania). On the sites of investigation, the monthly concentrations of NO<sub>2</sub> and SO<sub>2</sub> were determined by passive diffusion samplers. Four sites near the factory with 39–68-year-old *Pinus sylvestris* L. (stands belonging to *Carico-sphagno-Pinetum* or *Vaccinio-myrtillo-Pinetum*) were selected for sampling: site A1 (at a distance of 0.5 km from the factory); site A2 (1.5 km); site A3 (3.5 km) and site A4 (10.0 km). In 1996 the trees were visually evaluated with respect to defoliation (46% – A1; 27% – A2; 28% – A3; 23% – A4) and needle retention (1.99 – A1; 2.56 – A2; 2.40 – A3; 2.40 – A4). Sampling was done in every September. Estimation of the contact angles (CA) of water droplets, determination of chloroform-extractable wax and dust, needle surface rating into classes according to the area covered with structural wax (SW) were done as described earlier [11, 12].

## RESULTS AND DISCUSSION

In 1994–1996, needle stomatal area covered with SW varied from 52.0 to 76.1% on c needles and from 16.5 to 55.4% on c+1 needles (Fig. d-e). The c+1

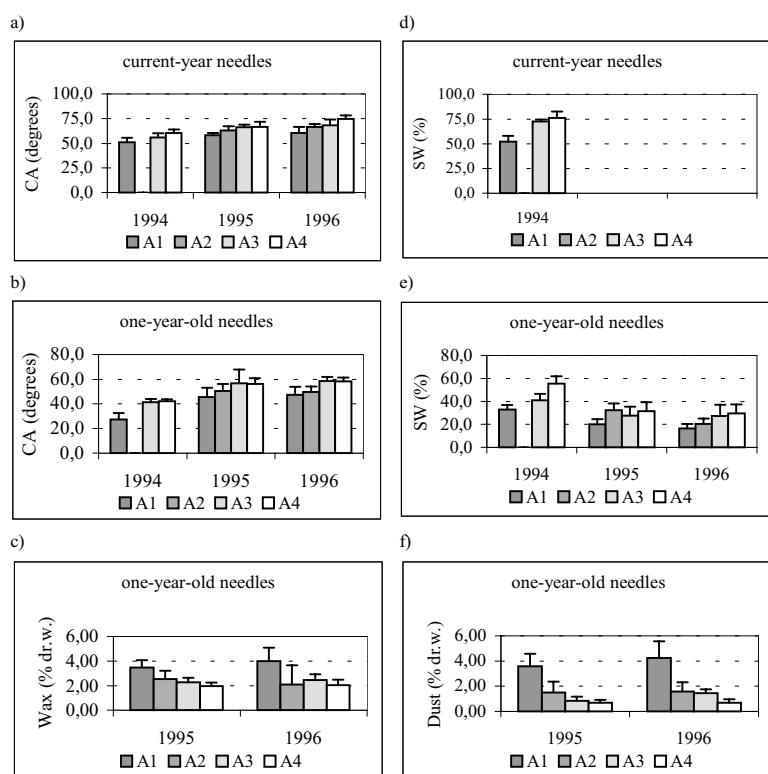


Figure. Mean values of contact angles (CA – a, b) of water droplets on the needles, amount of surface wax as % of dry weight (c), area (%) covered by structural wax (SW – d, e), amount of insoluble surface material (dust) as % dry weight (f) of *Pinus sylvestris* growing in sites located at different distance from the cement factory (bars above columns = standard deviations)

needles exhibited a significantly more degraded wax structure than did c needles. In all cases needles taken from site A1 had significantly ( $p < 0.05$ ) larger areas covered with eroded wax than had needles from the farther located site A4.

At the same time, CA on c needles ranged between 50.9–74.7° and 27.3–58.5° on c+1 needles (Fig., a–b). Wettability was significantly higher for c+1 than for c needles. Differences ( $p < 0.05$ ) between sites A1 and A4 according to the CA values on c needles were found reliable in all three-year-period and for c+1 needles in two of three years. Like c needles, c+1 needles from the highest pollu-

**Table 1. Main effects of needle age, site and year of sampling, and their interaction tested by ANOVA for *Pinus sylvestris* needle area covered by structural wax (SW) and contact angles (CA) of water droplets**

Variable	Needle age	Site	Year	Interaction			
	1	2	3	1,2	1,3	2,3	1,2,3
SW	***	***	***	n.s.	n.s.	**	n.s.
CA	***	***	***	n.s.	*	n.s.	n.s.

Statistical significances: \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; n.s. = non-significant

tion site A1 had lower CA values than had the needles taken from the farthest site A4. In most cases SW and CA data did not reveal significant differences between site A1 and site A2 or site A3. Assessment of needle surface SW and CA revealed significant differences related with needle age, site and year of sampling (Table 1).

A reliably larger amount of wax (Fig., c) covered needles taken from site A1 than from all other sites ( $p < 0.01$ ). the same tendency was in surface dust amount differences among the sites: site A1 needles had significantly ( $p < 0.01$ ) more dust than had needles of all the other sites (Fig., f).

Significant correlations were found between CA and SW for c and c+1 needles ( $r = 0.610$ ,  $p < 0.01$ ;  $r = 0.223$ ,  $p < 0.05$ , respectively), between CA and wax amount ( $r = -0.599$ ,  $p < 0.001$  for c needles;  $r = 0.223$ ,  $p < 0.05$  for c+1 needles), between CA and dust amount ( $r = -0.709$ ,  $p < 0.001$  for c needles;  $r = -0.635$ ,  $p < 0.001$  for c+1 needles). The correlations between air pollutant concentrations and CA or SW were higher for c+1 than for c needles (Table 2). Opposite data have been obtained for the dust and wax

amount. The regression coefficients of the curves describing a relationship between SW, CA and distance were generally low:  $SW = 21.85 + 1.98 \cdot \text{distance}$ ;  $p < 0.001$ ;  $r^2 = 0.31$ ; mean standard error,  $MSE = 11.26$ ;  $CA = e^{3.98 - 0.16/\text{distance}}$ ;  $p < 0.001$ ;  $r^2 = 0.24$ ;  $MSE = 11.26$ .

In the study area, the concentration of  $NO_2$  estimated by diffusion samplers in March 1994 ranged within 5.8–3.8  $\mu\text{g m}^{-3}$  and in October 1999 from 3.2 to 1.8  $\mu\text{g m}^{-3}$ , while the  $SO_2$  concentration was

**Table 2. Spearman's rank correlation between needle surface variables and air pollutant concentration, site distance from the pollution source**

Parameter	SW	CA	Wax	Dust
current-year needles				
Distance	0.301*	0.358***	-0.756***	-0.884***
$SO_2$	ns	-0.250***	0.730***	0.748***
$NO_2$	ns	-0.307***	0.780***	0.861***
one-year-old needles				
Distance	0.515***	0.452***	-0.568***	-0.793***
$SO_2$	-0.360***	-0.475***	0.630***	0.622***
$NO_2$	-0.445***	-0.486***	0.629***	0.710***

Statistical significances: \* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$ ; n.s. = non-significant

higher ( $5.5\text{--}2.7\ \mu\text{g m}^{-3}$ , October 1999). Wet deposition and soil analyses done in 1995 showed that alkalisation process as well as  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and trace metal accumulation was going on at a distance of up to 5–6 km [9]. In addition, near the factory elevated concentrations of Ca, Fe, Zn, Pb, Co, Sr were found in c needles of the same Scots pine trees [5]. These data show that higher wax erosion of Scots pine needles near the factory could mainly be attributed to the cement dust effects.

The damage of leaf surface could influence the general vitality of the trees. Higher wax erosion on the needle surface coincides with the higher defoliation of the trees ( $r = -0.486$ ;  $p < 0.001$ ). Values of SW found in the present study were slightly higher than those detected for the needles near the other local pollution sources in Lithuania; they are in agreement with differences in the amount of emissions of comparable factories [8, 11]. Contrary to data on SW, the values of CA near the cement factory were the lowest in comparison with the other main industrial areas. It shows that, in addition to wax erosion, dust has a strong wettability-increasing effect. The present study has shown obvious effects of alkaline dust on CA and wax amount, while few effects were documented for the same parameters near the other sources of pollution in Lithuania. A reliable correlation found between CA and chloroform-insoluble material amount on the needles shows the validity of CA parameter for evaluation of dust pollution. The correlation between the year of investigation and CA data for c+1 needles ( $r = 0.502$   $p < 0.001$ ) is in agreement with a decreasing amount of dust emission within the period of investigation. Some studies have shown that air pollutants may increase the amount of wax [13], and data of the present research are in support to it. Alkaline dust-induced changes in lignin content in the needles have been already described [3, 4]. The needle surface parameters studied show that the present lower level of pollutants still is able to induce a detectable damage of needle surface.

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#### PAPRASTOSIOS PUŠIES SPYGLIŲ PAVIRŠIAUS SAVYBĖS CEMENTO DULKIŲ APLINKOJE

#### S a n t r a u k a

Buvo per 3 metus įvertintas AB „Akmenės cementas“ poveikis paprastosios pušies spyglių paviršiui. 10 km intervale pasirinkti 4 tyrimo taškai. Spyglių paviršiaus ploto, padengto struktūriniu vašku, ir sudrėkstamumo (t. y. vandens lašo kontakto kampų) matavimai parodė, kad spyglių paviršiaus būklė reikšmingai ( $p < 0,05$ ) blogiausia artimiausiai gamyklos esančiame taške. Šiame tyrimo taške rastas didžiausias vaško ir dulkių kiekis spyglių paviršiuje. Didesnė taršos indikacinė vertė pasižymėjo antramečių spyglių plotas, padengtas struktūriniu vašku, ir sudrėkstamumas bei pirmamečių spyglių vaško ir dulkių kiekis spyglių paviršiuje.