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Susceptibility of European *Pinus sylvestris* L. populations to SO_2, NO_2, SO_2+NO_2 and HF under laboratory and field conditions

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Abstract

Under controlled laboratory conditions, 1-3 year-old *Pinus sylvestris* seedlings were exposed to SO_2 (0.75 $mm^3\ dm^{-3} \times 5$ days, 6h daily), NO_2 (0.5 $mm^3\ dm^{-3} \times 66$ days, 6h daily), SO_2+NO_2 (0.25 $mm^3\ dm^{-3}$ + 0.5 $mm^3\ dm^{-3} \times 19$ days, 6h daily) and HF (0.25 $mm^3\ dm^{-3} \times 4$ days, 6h daily). Seedlings of the same provenances had also been outplanted near two types of emission sources which pollute the environment with SO_2 and fluorides, and with SO_2 and heavy metals. Nitrogen dioxide did not cause visible symptoms of injury to plants. Exposition of plants to the action of other pollutants differentiated the studied populations in respect to the size of needle necroses. In general, northern (Sweden, USSR) and southern (Turkey, Yugoslavia) populations demonstrated lower sensitivity than pines from the more central parts of the species' range in Europe. A statistically significant correlation was shown between the injuries to seedlings observed in the field and under laboratory conditions.

Key words: air pollution, needle necrosis, Scots pine, pollution tolerance, provenance

INTRODUCTION

The main forest-forming species of Poland, namely Scots pine (*Pinus sylvestris* L.) demonstrates a variability in sensitivity to toxic pollutants. This was observed both on the individual (Oleksyn 1981) and clonal (Białobok et al. 1980) level. From the late sixties, experiments are in progress aimed at determining the degree of population variability in the sensitivity of the species to some industrial gases such as SO_2 (Vogl 1969, Schütt et al. 1970, Oleksyn and Białobok 1986), O_3 (Demeritt 1977) and mixtures of gases in field conditions (Huttunen 1978, Huttunen and Törmälehto 1982, Oleksyn 1983, Oleksyn and Białobok 1986).

Results of experiments conducted so far indicate that there exists a relationship between the sensitivity of individual Scots pine populations to air pollution and the thickness of epidermal cells (Huttunen 1978), the intensity of photosynthesis (Oleksyn and Białobok 1986) and the content of free proline (Karolewski – in press).

The objective of the investigations presented in this publication was to determine the differentiation of sensitivity of individual populations of Scots pine, originating from a major part of the range of the species in Europe, to selected industrial fumes and their combinations. We also wanted to test to what extent the sensitivity of various Scots pine provenances, as determined on the basis of laboratory tests, is confirmed in the field conditions.

MATERIALS AND METHODS

PLANT MATERIAL

Seedlings of *Pinus sylvestris* exposed to the action SO_2, NO_2, SO_2+NO_2 and HF were raised in pots on a medium composed of a mixture of forest soil and peat at a ratio of 3:1. In the studies use was made of plants obtained from seeds collected in the years 1978-1980 in order to establish an international

Table 1

Information on the origin of seeds used in the study

Provenance, No	Origin	Country	Lat. (N)	Long. (E)	Altitude (m)
1	Roščinskaya Dača	USSR	60°15′	29°54′	80[a]
2	Kondežskoe	USSR	59°58′	33°30′	70[a]
3	Serebryanskoe	USSR	58°50′	29°07′	80[a]
4	Silene	USSR	55°45′	26°40′	165
5	Miłomłyn	Poland	53°34′	20°00′	110
6	Supraśl	Poland	53°12′	23°22′	160
7	Spała	Poland	51°37′	20°12′	160
8	Rychtal	Poland	51°08′	17°55′	190
9	Bolewice	Poland	52°24′	16°03′	90
10	Neuhaus	GDR	53°02′	13°54′	40
11	Betzhorn	FRG	52°30′	10°30′	650
12	Lampertheim	FRG	50°00′	10°00′	95-100
13	Ardennes	Belgium	50°46′	4°26′	110
14	Haguenau	France	48°49′	7°47′	130-180
15	Sumpberget	Sweden	60°11′	15°52′	185
16	Zahorie	Czechoslovakia	48°46′	17°03′	160
17	Pornóapáti	Hungary	47°20′	16°28′	400
18	Maočnica	Yugoslavia	43°10′	19°13′	1200
19	Prušacka Rijeka	Yugoslavia	44°05′	17°21′	800-970
20	Çatacik	Turkey	40°00′	31°10′	1380-1420

[a] Approximate data.

provenance experiment by IUFRO (International Union of Forestry Research Organisations) Working Party "Breeding Scots Pine". Information about the plant material used in the experiment is presented in Table 1.

The experiments were conducted on one-year-old seedlings (SO_2 and NO_2), on 2-year-old ones (SO_2+NO_2) and 3-year-old ones (HF). The field experimental areas were established using 2-year-old seedlings.

EXPOSITION OF PLANTS TO GASES UNDER LABORATORY CONDITIONS

The seedlings were treated with SO_2 (14-23 seedlings from each provenance), NO_2, the SO_2+NO_2 mixture (3 seedlings per provenance) and HF (4 seedlings per provenance), in chambers specially constructed for this purpose (Białobok et al. 1978, 1980). Dosing and monitoring of sulphur dioxide (0.75 mm^3 $dm^{-3} \times 5$ days, 6h daily) was performed automatically using a Mikolyt-2 type analyser (Junkalor, GDR).

Dosing and monitoring of nitrogen dioxide (0.5 mm^3 $dm^{-3} \times 66$ days, 6h daily) was performed with the help of a Mast 727-21 analyser (Mast Development Co., USA).

In the case where a SO_2+NO_2 mixture (0.25 mm^3 dm^{-3} + 0.5 mm^3 $dm^{-3} \times 19$ days, 6h daily) was used, the air for analysis of SO_2 was taken from a site prior to NO_2 addition, and the concentration of NO_2 was determined in air passed through a filter absorbing SO_2 (Mast 725-30, Mast Development Co., USA).

Hydrogen fluoride (0.25 mm^3 $dm^{-3} \times 4$ days, 6h daily) was determined colorimetrically using the zirconium alizerin method described by Bumsted and Wells (1952).

During the exposition of plants to the gases the air temperature varied between 20 and 26°C, relative humidity was 55-70% and there were about 15 changes of air in the chambers per hour. Natural illumination was employed with artificial light from an incandescent-mercury lamp added at 35-75 $W \times m^{-2}$.

The mean percentage of injured leaf surface was taken as the measure of the sensitivity of individual populations of pine to the gases. The data obtained in this manner was verified statistically using the new multiple range test of Duncan (Oktaba 1976).

All of the experiments were conducted in the months of August and September. According to the data of Schönbach et al. (1968) the end of the vegetation season is the best time for this type of studies.

DESCRIPTION OF THE EMISSION SOURCES NEAR WHICH FIELD PLANTATIONS WERE LOCATED

Poznań Factory of Phosphate Fertilizers (PFPF)

The provenance experiment was established in the spring of 1984 about 2 km from the factory. The experiment consisted of 4 blocks, each with 20 plots. On each plot, a total of 20 plants were outplanted. The area is located on postagricultural land, uniform in terms of soil conditions. A schematic plan of the area and its detailed description is given in an earlier paper (Oleksyn and Białobok 1986).

PFPF produces a dust and granulated superphosphate fertilizer. The raw material is mainly phosphorite (Maszner 1979). Besides superphosphate sulphuric acid is also produced in PFPF by the contact method. After the liquidation in 1981 of the instalations for the production of sulphuric acid by the nitrose method, the emission of nitrogen oxides into the atmosphere ceased. The main substances with which PFPF pollutes the environment are (J. Kończal – personal communication): 1) sulphur oxides, calculated as SO_2, about 40 kg h^{-1}; 2) fluorine compounds, calculated as F about 11 kg h^{-1}.

The fluorine compounds are emitted primarily in the form of silicon tetrafluoride (SiF_4). This is a postabsorption gas emitted during production of superphosphate.

In the years 1971-1974, the monthly soil deposits (primarily in the form of compounds of calcium, phosphorus, sulphur and lead) varied from 4.3 to 78.9 t km^{-2}. The highest emissions of these substances were noted in August and October. In view of the fact that PFPF undertook modernisation efforts, lately the level of dust deposit was reduced to a large extent.

In soils close to PFPF, a considerable accumulation of fluorine compounds was found. The apatite of fluorine forming there is difficult to dissolve in water. This substantially reduces its toxic influence on the soil in the region.

Copper smelter in Głogów

The experimental area with Scots pine provenances was established in the spring of 1984 at a distance of 3.5 km E from the main emission sources, namely the smelters Głogów I and Głogów II. The area consists of 3 blocks with 18 plots each. Twenty plants were outplanted on each plot.

According to the Main Statistical Office (Ochrona... 1986) in 1985 the emission of SO_2 from the copper smelters Głogów I and Głogów II was 56 594 t $year^{-1}$, CO_2 129 762 t $year^{-1}$ and dusts – 3 271 t $year^{-1}$. The total magnitude of gaseous and dust air pollutants ranks these smelters in 6th place among the most noxious industrial plants in Poland.

The mean annual concentration of SO_2 in the years 1975-1982 measured near the experimental area, in the village of Bogomice, varied from 0.02 to 0.07 mm^3 dm^{-3}, with the maximal daily concentrations from 0.13 to 3.06 mm^3 dm^{-3} (M. Wierzbicki – personal communication).

In view of the considerable emission of metallic dusts, soils in the vicinity of the smelters are characterized by high concentrations of Cu, Pb, Zn and other heavy metals. The concentration of Cu and Pb in the upper layers of the soil (0-20 cm) attained very high levels near the experimental area. The total Cu content varies within the limits of 250-300 ppm but sporadically attains even

3200 ppm, and the total concentration of Pb is equal to 450-500 ppm, attaining in places up to 1000 ppm (Roszyk 1978, Kabata-Pendias 1978, 1979).

RESULTS AND DISCUSSION

The results of needle necroses formed as a consequence of exposition to pollutants under laboratory and field conditions are shown in Table 2. As can be seen from the data presented there, nitrogen dioxide even after a relatively long period of exposition (0.5 mm^3 $dm^{-3} \times 66$ days, 6h daily) did not cause the formation of visible symptoms of injury to needles in the form of necroses or discolorations. This confirms the already reported (MacLean 1977, Oleksyn 1984) relatively low toxicity of NO_2 in situation where it is the only gas acting in the given environment.

Table 2

Sensitivity of one-year-old needles from various *Pinus sylvestris* populations to the action of SO_2, NO_2, SO_2+NO_2 nad HF under laboratory conditions and SO_2+fluorides (Luboń) and SO_2+heavy metals (Głogów) in the open air

Prevenance, No.[a]	% Needles injured					
	SO_2[d]	NO_2	SO_2+NO_2	HF	Luboń[d]	Głogów
1	6.67ab[b]	0.00	11.00a	3.50a	6.57[c]	1.43a
2	5.94a	0.00	29.00a	0.25a	3.09ab	1.92ab
3	–	–	–	–	3.20ab	1.61a
4	19.78abc	0.00	–	15.00ab	6.56abcde	4.77abc
5	39.68ef	0.00	2.50a	0.25a	10.86def	5.15abc
6	41.87fg	0.00	–	8.75a	10.96ef	6.13abc
7	43.61fg	0.00	22.25a	1.50a	10.20cdef	5.84abc
8	33.88cdef	0.00	2.00a	5.75a	13.25f	15.95d
9	25.45cde	0.00	–	3.75a	–	–
10	38.46def	0.00	–	10.00a	4.35abc	7.08abcd
11	23.50cd	0.00	12.00a	2.50a	4.60abcd	4.74abc
12	38.43def	0.00	–	6.25a	9.16bcdef	9.40abcd
13	58.46g	0.00	24.00a	2.50a	4.49abc	4.53abc
14	32.17cdef	0.00	5.50a	31.25b	12.88ef	11.71cd
15	7.63ab	0.00	1.25a	1.25a	3.35ab	1.23a
16	33.46cdef	0.00	8.75a	0.25a	7.86bcdef	11.05bcd
17	–	–	–	–	12.64ef	11.05bcd
18	25.00cde	0.00	–	1.25a	8.92bcdef	2.66abc
19	21.43bc	0.00	3.25a	1.50a	4.17abc	7.75abcd
20	21.05bc	0.00	0.25a	0.50a	1.33a	–
Mean	27.18	0.00	10.14	5.33	7.29	6.33

[a] See Table 1 for origin, [b] Values indicated by the same letter are not significantly different with a confidence level of $\alpha = 0.05$ as determined by the new multiple range test D (Oktaba 1976). [c] There is only one plot with seedlings of this provenance on the experimental area. [d] From Oleksyn and Białobok (1986).

In all of the studied provenances of Scots pine, we found visible symptoms of injury to the needles as the result of exposure to a mixture of SO_2 and NO_2. However in view of the considerable differentiation in the sensitivity of individual seedlings within a provenance, these differences were not statistically significant on the provenance level.

In the case of all other pollutants, both under laboratory and field conditions, the provenances studied by us were characterized by significant statistical differences in the magnitude of injury to needles (Table 2). The greatest tolerance to industrial pollutants in which SO_2 dominated was shown by provenances originating from the northern part of the species' range in Europe (Sweden, USSR) and also partially from the outlier populations in southern Europe (Turkey, Yugoslavia). As we have pointed out earlier (Oleksyn and Białobok 1986), the higher tolerance of these populations my be associated with their relatively lower productivity and photosynthetic efficiency, which are factors with which the sensitivity of the species to toxic pollutants is correlated.

It needs to be emphasized that populations of pine from the regions mentioned above (except provenance Silene – USSR) are not suitablė for wider introduction into Poland in view of their low survival and low productivity in our climatic conditions (Giertych and Oleksyn 1981, Oleksyn and Giertych 1984).

The results quoted above concerning provenance differentiation in sensitivity of *P. sylvestris* to industrial pollution of air appear to confirm the observations of Gerhold (1977) who, on the basis of an analysis of literature data, came to the conclusion that populations from cool, dry and more continental regions are less sensitive to toxic gases.

From the values of the correlation coefficients presented in Table 3 it can be seen that the greatest agreement is to be found between the sensitivity of seedlings of Scots pine populations grown near the emission source of SO_2 and fluorides (PFPF) and the sensitivity of those grown under exposition to SO_2 and heavy metals (Głogów). This might indicate that the dominant role in the formation of necroses on needles both in the area in Luboń (PFPF) and Głogów is played by the same factor, which most probably is sulphur dioxide. This is confirmed by statistically significant correlations between the intensity of necrosis formation on needles caused by SO_2 under laboratory conditions and the extent of injury in individual populations in both of the field experiments (Table 3).

Lack of a significant relationship (Table 3) between the necroses of seedlings of *P. sylvestris* exposed to SO_2, SO_2+NO_2 and HF is probably caused by differences in the mode of action of these pollutants on the physiological processes and on the metabolism of plants (Karolewski 1988). This is also confirmed by our earlier studies on the action of SO_2, NO_2 and HF on seedling progenies of several clones of Scots pine (Białobok et al. 1980).

Table 3

Matrix of correlation coefficients between the magnitude of needle necroses in various Scots pine populations exposed to the action of pollutants under field and laboratory conditions

	SO_2+NO_2	SO_2	HF	SO_2+fluorides (Luboń)
SO_2	0.17	–	–	–
HF	−0.17	0.12	–	–
SO_2+fluorides (Luboń)	−0.17	0.44*	0.43*	–
SO_2+heavy metals (Głogów)	−0.41	0.44*	0.39	0.69**

* Correlation coefficient significant at a confidence level of $\alpha = 0.1$.

** Correlation coefficient significant at a confidence level of $\alpha = 0.01$.

It is well known that in the conditions of a polluted environment, numerous stress factors, both abiotic and biotic, affect plants simultaneously. Thus, it was suggested (Karnosky 1981) that it is necessary to conduct special studies in order to obtain an answer to the question as to whether short-term laboratory experiments are reproducible in field conditions. The results presented in this study (Table 3) indicate that there exist significant correlations between the sensitivity of various populations of *P. sylvestris* to the action of sulphur dioxide under laboratory conditions and their sensitivity in field experiments (Luboń, Głogów). This would indicate that laboratory experiments can be considered useful in practice when determining the tolerance of trees to the action of toxic gases.

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Wrażliwość europejskich populacji Pinus sylvestris L na działanie SO_2, NO_2, SO_2+NO_2 i HF w warunkach laboratoryjnych i polowych

Streszczenie

W kontrolowanych warunkach laboratoryjnych eksponowano 1-3 letnie siewki *Pinus sylvestris* na działanie SO_2 (0,75 mm^3 dm^{-3} × 5 dni, 6h dziennie), NO_2 (0,5 mm^3 dm^{-3} × 66 dni, 6h

dziennie), SO_2+NO_2 (0,25 mm^3 dm^{-3}+0,5 mm^3 $dm^{-3}\times$ 19 dni, 6h dziennie) i HF (0,25 mm^3 $dm^{-3}\times$4 dni, 6h dziennie). Siewki tych samych prowieniencji wysadzono także w pobliżu dwóch typów źródeł emisji zanieczyszczających środowisko SO_2 i fluorkami oraz SO_2 i metalami ciężkimi. Dwutlenek azotu nie wywołał widocznych objawów uszkodzenia siewek. Ekspozycja roślin na działanie pozostałych zanieczyszczeń różnicowała badane populacje pod względem wielkości nekroz igieł. Na ogół północne (Szwecja, ZSRR) i południowe populacje sosny (Turcja, Jugosławia) wykazywały mniejszą wrażliwość niż populacje pochodzące z centralnej części zasięgu tego gatunku w Europie. Między uszkodzeniami siewek w warunkach polowych i laboratoryjnych istnieje statystycznie istotna korelacja.