PHOSPHATE STATUS AND ACID PHOSPHATASE ACTIVITY IN SOIL AND ECTOMYCORRHIZAS IN TWO MATURE STANDS OF SCOTS PINE (*PINUS SYLVESTRIS* L.) EXPOSED TO DIFFERENT LEVELS OF ANTHROPOGENIC POLLUTION

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ABSTRACT

The relations between anthropogenic environmental pollution and the level of inorganic phosphorus in soil, enzyme activities of extracellular soil acid phosphatase and the surface acid phosphatase of excised ectomycorrhizas of Scots pine (*Pinus sylvestris* L.) were studied. Soil and root samples were taken from two Scots pine stands in central Poland: a polluted site exposed to long-term pollution from a steelworks and the city of Warsaw and a reference plot (control) free from direct impact of pollution. The polluted site was characterised by high concentration of trace elements (Cd, Pb, Cu, Zn, Mn, Cr) and low level of inorganic phosphate in soil. This site had significantly lower enzyme activities of soil acid phosphatase (0.54 $\mu\text{moles } p\text{-nitrophenol released g}^{-1} \text{ dry weight h}^{-1}$) and surface acid phosphatase of pine ectomycorrhizas (3.37 $\mu\text{moles } p\text{-nitrophenol released g}^{-1} \text{ fresh weight h}^{-1}$) than the control site (1.36 $\mu\text{moles } p\text{-nitrophenol released g}^{-1} \text{ dry weight h}^{-1}$ and 12.46 $\mu\text{moles } p\text{-nitrophenol released g}^{-1} \text{ fresh weight h}^{-1}$, respectively). The levels of phosphate, carbon and nitrogen in pine fine roots were also analysed. Low concentrations of $\text{PO}_4\text{-P}$ and high N: P ratio in pine fine roots from polluted site were found. The results suggest that soil pollutants may have a negative effect on the extracellular acid phosphatase of soil and Scots pine ectomycorrhizas and on the phosphorus status in fine roots of the plant.

KEY WORDS: Air pollution, heavy metals, microbial vitality, phosphomonoesterase, phosphorus.

INTRODUCTION

Ectomycorrhizas are common symbiotic structures developed by ectomycorrhizal fungi and fine roots of trees in forests of boreal and temperate regions, as well as in some tropical ecosystems. Ectomycorrhizal fungi and ectomycorrhizas are known to enhance the uptake of nutrients by plants from the soil solution (Harley and Smith 1983). Forests dominated by ectomycorrhizal trees grow generally on acidic soils, with high accumulation of organic residues at the soil surface and limited availability of nutrients. A majority of total phosphorus in forest soils is normally bound to organic complexes unavailable to plants (Fernandez and Struchemeyer 1985; Zech et al. 1987). Deposition of heavy metals combined with soil acidification, especially at poor forest stands, may cause a mobilisation and increased availability of toxic metals and accelerated leaching of essential cations down to the soil profile. Heavy metals may decrease the vitality of soil microorganisms (Kuperman and Carreiro 1997) and inhibit decomposition rate of litter organic matter (Zwoliński 1995; Breyer et al. 1997).

Ectomycorrhizas are able to store large amounts of P in the ungal sheaths and to release it to the plant when its supply is limited (Morrison 1962). Up to 75% of the P uptake of co-

ferous trees may be derived from the organic fraction of soil (Firsching and Claassen 1996). One of the mechanisms by which mycorrhizal fungi and mycorrhizas may increase the uptake of phosphorus from soil is the production of surface-accessible acid phosphatase (acid phosphomonoesterase, AcPase, EC 3.1.3.2) (Harley 1989; Smith and Read 1997), localised in ectomycorrhizal root tips and the extramatrical mycelium penetrating the soil substrate. In ectomycorrhizas of *Pinus pinaster* with fungus *Pisolithus arrhizus* the activity of AcPase has been detected mainly in the matrix of the fungal mantle and along the plasma membranes of the Hartig net (Dexheimer et al. 1986; Turnau and Dexheimer 1995). This enzyme is released into the rhizosphere by plant roots, mycorrhizas and soil microorganisms (fungi, bacteria, algae) and may exist temporarily in complexes enzyme-substrate, adsorbed to clay minerals or be associated with humic colloids (Burns 1982). The soil extracellular enzyme takes part in hydrolysis of polyphosphates and organic phosphates in soil (Boutin and Roux 1974) and in P absorption by the plant (Bielecki 1973).

The root-surface AcPase has been shown more active in ectomycorrhizal than on non-mycorrhizal roots of *Fagus sylvatica* (Bartlett and Lewis 1973, Williamson and Alexander 1975), *Pinus resinosa* (MacFall et al. 1991), *P. sylvestris* (Kieliszewska-Rokicka 1992a) and *P. pinca* (Pasqualini et al. 1992), although recently Cumming (1996) reported activity of

this enzyme to be greater in non-mycorrhizal roots of young seedlings of *P. rigida* than in roots colonised with ectomycorrhizal fungi. The activity of AcPase can vary between ectomycorrhizal morphotypes (Antibus and Linkins 1992) and exhibit seasonal variation with maximum activity in autumn (Rejšek 1991; Antibus and Linkins 1992).

Physiological activity of mycorrhizas and soil microorganisms are known to be influenced by such factors as soil type and fertility, climatic conditions or anthropogenic pollution. Activity of non-specific phosphatase has been shown to be inversely related to phosphate supply, both in soil (Spiers and McGill 1979) and in ectomycorrhizal root tips (Alexander and Hardy 1981; MacFall et al. 1991; Kieliszewska-Rokicka 1992a; Pasqualini et al. 1992). The soil AcPase was depressed by trace elements (Juma and Tabatai 1977; Tyler 1974) and the root-surface AcPase had decreased activity in plots naturally or artificially polluted by sulphur (Rejšek 1991).

This study was conducted to determine the phosphate status and the activities of extracellular acid phosphatases in an environment disturbed by a pressure of industrial/urban pollution, where contribution of heavy metals in soil exceed levels considered as normal (Kabata-Pendias and Pendias 1979).

MATERIAL AND METHODS

Study sites

Two study sites were established in central Poland in the vicinity of Warsaw: a polluted site located 200 m from the Warsaw Steelworks and a control site situated in the Kampinos National Park, about 10 km upwind from the Warsaw Steelworks, outside of direct effects of industrial and urban pollution (Molski and Dmuchowski 1990). At the polluted site the average annual SO_2 concentration was $33 \mu\text{g m}^{-3}$ and maximum 24 h concentration $74 \mu\text{g m}^{-3}$; the average NO_2 concentration was $33 \mu\text{g m}^{-3}$ and maximum 24-h concentration was $127 \mu\text{g m}^{-3}$ (Chmielewski and Dmuchowski 1994). At the control site the average SO_2 and NO_2 concentrations were below $10 \mu\text{g m}^{-3}$ (Molski and Dmuchowski 1990; Dmuchowski and Bytnerowicz 1995). Chemical properties of soil at both the sites, characterised by podsolc soil of the same origin, have been presented by Kurczyńska et al. (1993, 1997). The content of heavy metals in soil horizon A_{FH} (2–4 cm) at the polluted site located near the Warsaw Steelworks has been reported as follows: Cd – 8.44 ppm, Pb – 254 ppm, Cu – 94.8 ppm, Cr – 99 ppm, Zn – 1558 ppm, Mn – 766 ppm, Fe – 9240 ppm. Lower content of the metals was found in this soil horizon in the Kampinos National Park (control): Cd – 0.36 ppm, Pb – 41 ppm, Cu – 14, Cr – 32.4, Zn – 46.8 ppm, Mn – 152 ppm, Fe – 4320 ppm. Lower concentration of alkaline cations was detected in this soil layer at the polluted site (K^+ – 0.75 meq 100 g^{-1} , Na^+ – 1.52 meq 100 g^{-1} , Ca^{2+} – 7.93 meq 100 g^{-1} , Mg^{2+} – 2.12 meq) than at the control site (K^+ – 0.65 meq 100 g^{-1} , Na^+ – 3.88 meq 100 g^{-1} , Ca^{2+} – 48.7 meq 100 g^{-1} , Mg^{2+} – 11.33 meq 100 g^{-1}).

Sampling and sample preparation

Soil core samples were collected in October with a 5 cm diameter soil corer to a depth of 10 cm after removal of the litter layer. Three cores were taken at 0.7–1 m from the bases of six 25-year-old Scots pine trees at each study site. Intact soil cores were sealed in plastic bags and kept frozen until used. Soil was sieved < 2 mm and AcPase activity and soil microbial vitality were analysed. Fine roots were separated from soil and organic matter on a sieve under a stream of

cold water, excised from the main root and cleaned with running water to remove adhering organic matter. Final separation of roots was conducted under a stereomicroscope and vitality of ectomycorrhizas was estimated, based on colour and turgescence. Only ectomycorrhizas judged to be vital were chosen for further studies. Ectomycorrhizal morphotypes were distinguished according to morphological traits (shape, colour and surface texture) and different morphotypes were analysed separately.

Activity of root surface acid phosphatase

AcPase activity associated with excised ectomycorrhizal root tips was measured using the modified method of Bartlett and Lewis (1973). The incubation medium contained 1.8 ml of 0.1 M Na-acetate buffer, pH 5.0, 0.2 ml 0.05 M *p*-nitrophenyl phosphate (*p*NPP) and 10–20 mg fresh weight of root tips. In the control sample (blank) roots were omitted. After 1 h in a shaking bath at 30°C, the roots were removed and 1 ml of reaction mixture was added to 9 ml of 0.5 M NaOH. The liberated *p*-nitrophenol (*p*NP) was determined at 400 nm. Enzyme activity was expressed as $\mu\text{moles pNP g}^{-1}$ fresh weight h^{-1} .

Activity of soil acid phosphatase

Two ml of 0.2 M phosphate buffer (pH 6.5), 0.5 ml of 0.115 M *p*-nitrophenyl phosphate (*p*NPP) and 0.1 ml of toluene were added to 0.5 g of soil and incubated at 37°C for 1 h. Adding of 2 ml of 0.5 M NaOH and 0.5 ml of 0.5 M CaCl_2 stopped the reaction. After filtration the solution was 10 times diluted and the liberated *p*-nitrophenol was determined at 400 nm (Tabatabai and Bremner 1969). Each sample was accompanied by a reference sample, where *p*-NPP was omitted.

Vitality of soil microorganisms

Dehydrogenase activity (DHA) was measured in soil samples using the tetrazolic method after Thalman (1968) as a criterion of microbial vitality. Soil samples (2.5 g) were incubated in 5 ml of 0.5 M Tris buffer, pH 8.0, containing 1% triphenyltetrazolic 2,3,5-chloride (TTC), for 24 hours at 30°C in darkness. The triphenyltetrazolium formazan (TTF) resulting from enzymatic reaction was extracted with 96% ethanol and measured spectrophotometrically at 480 nm. Enzyme activity was expressed as nmol of TTF g^{-1} dry soil 24 h^{-1} . DHA was measured in 12 soil samples per each site.

Soil analyses

The pH of the soil layer from which roots were removed was measured with a glass electrode in soil-water and soil-salt (0.01 M CaCl_2) suspensions (Manual on methods and criteria 1994).

The analyses of available phosphorus and hydrogen ions (P_2O_5 , H^+) were carried out according to standard research methods (Ostrowska et al. 1991).

Chemical analyses of fine roots

Phosphorus concentration was measured using a standard colorimetric method (Allen 1989). Carbon and nitrogen content were estimated by use of isotope ratio mass spectrometer (IRMS) Europa 20-20.

Statistics

Statistical differences in enzyme activity among mycorrhizal morphotypes and between the study sites were established using analysis of variance and LSD (Statistica 5.0).

RESULTS

Phosphate content in soil

The average concentration of extractable P, measured as P_2O_5 , in the upper soil layer (0-10 cm) was almost three times lower at the polluted site (Warsaw Steelworks) than at the non-polluted plot in the Kampinos National Park. The pH of the unpolluted soil in this soil horizon was slightly lower than pH of the polluted soil (Table 1).

TABLE 1. Concentration of inorganic P in the upper soil layer (0-10 cm) and soil acidity in the Kampinos National Park (control site) and the Warsaw Steelworks (polluted site). Data are means $\pm$ standard deviation ($n=4$).

Soil properties	Kampinos National Park	Warsaw Steelworks
Pi (mg $P_2O_5 \cdot 100\text{ g}^{-1}$ of soil)	8.30 ± 1.05	3.10 ± 0.82
H^+ (meq $\cdot 100\text{ g}^{-1}$ of soil)	0.041 ± 0.005	0.037 ± 0.016
pH _{water}	4.62 ± 0.16	6.54 ± 0.26
pH _{salt}	3.84 ± 0.15	5.93 ± 0.20

Description of ectomycorrhizal morphotypes

Ten morphotypes formed on Scots pine roots were distinguished in root samples (0-10 cm depth) at the two pine stands.

Type A: Yellow to yellow-brownish, a smooth mantle surface, repeatedly dichotomously branched, emanating hyphae and rhizomorphs not observed ("*Pinirhiza lutea*" type, according to Mleczko 1996); Type B: Yellow-brown to brown smooth mantle with occasionally emanating hyphae, simple to branched; Type C: Yellow to light brown mantle, smooth, with silvery appearance, simple to dichotomously branched; Type D: Pale yellow and yellow smooth mantle, coralloid; Type E: Black mantle with emanating black hyphae stiffly radiating from mantle, simple to dichotomously branched; Type F: Black granular mantle, smooth or with dark brown, woolly extramatrical hyphae emanating from mantle, dichotomously branched to coralloid; Type G: Light-brown mantle with a fine net of extramatrical hyphae in cream colour, repeatedly dichotomously branched to coralloid; Type H: Brown, smooth mantle with abundant white extramatrical hyphae and rhizomorphs, simple, dichotomously branched to coralloid; Type I: Black, smooth mantle, no extramatrical hyphae, short coralloid; Type J: Pale yellow mantle, thick, short repeatedly dichotomously branched. Eight morphotypes were observed at the site in the Kampinos National Park and nine morphotypes at the plot near the Warsaw Steelworks. Some

differences in frequency of particular morphotypes were found between the two study sites (Fig. 1).

Root-surface acid phosphatase

The surface pNPP-ase activity of ectomycorrhizas ranged, depending on ectomycorrhizal morphotype, from 1.6 to 14 μmoles of p-NP g^{-1} fresh weight h^{-1} at the polluted site (Warsaw Steelworks) and from 3.6 to 39.0 μmoles of p-NP g^{-1} fresh weight h^{-1} at the control plot in the Kampinos National Park (Fig. 2). The ANOVA analysis showed that the mean enzyme activity of the root-surface acid phosphatase was significantly lower at the polluted than at the control site ($p < 0.001$).

Fig. 2. Enzyme activity of surface acid phosphatase (AcPase) of different ectomycorrhizal morphotypes of Scots pine trees at two forest stands in Poland influenced by different levels of air pollution: Kampinos National Park (relatively unpolluted site) and the Warsaw Steelworks (severe polluted site). The enzyme activity was expressed as moles pNP released $\cdot\text{g}^{-1}$ fresh weight $\cdot\text{h}^{-1}$. Means followed by the same letter did not differ significantly ($p < 0.001$) ($n=8-15$). The differences between the two study sites were statistically significant ($p < 0.001$) (Statistica 5.0).

Fig. 1. Frequency of ectomycorrhizal morphotypes of Scots pine at soil depth 0-10 cm at two forest stands in Poland influenced by different levels of air pollution: Kampinos National Park (relatively unpolluted site) and the Warsaw Steelworks (severe polluted site). Description of the morphotypes is presented above.

Soil microbial vitality and soil acid phosphatase activity

The enzyme activities of non-specific dehydrogenase in soil samples (0-10 cm depth) at the control site in the Kampinos National Park and at the polluted site in the vicinity of the Warsaw Steelworks were $15.4 \text{ nmol TTF g}^{-1} \text{ dry weight } 24 \text{ h}^{-1}$ and $13.9 \text{ nmol TTF g}^{-1} \text{ dry weight } 24 \text{ h}^{-1}$, respectively. The ANOVA analysis showed that the difference in soil DHA between the study sites was statistically insignificant (Fig. 3). The activity of extracellular AcPase in this soil horizon was statistically significantly lower in soil samples taken from the polluted site than from the control plot ($p < 0.001$) (Fig. 4).

Fig. 3. Soil dehydrogenase activity in two forest stands (0-10 cm depth) influenced by different levels of pollution: Kampinos National Park (relatively unpolluted site) and the Warsaw Steelworks (severe polluted site). The enzyme activity was expressed as $\text{nmol TTF} \cdot \text{g}^{-1} \text{ dry weight } 24 \text{ h}^{-1}$. Means followed by the same letter did not differ significantly ($n=12$).

Fig. 4. Acid phosphatase activity in soil taken from 0-10 cm depth at two forest stands in Poland influenced by different levels of air pollution: Kampinos National Park (relatively unpolluted site) and the Warsaw Steelworks (severe polluted site). The enzyme activity was expressed as $\mu\text{mol pNP released} \cdot \text{g}^{-1} \text{ dry weight} \cdot \text{h}^{-1}$. The differences between the sites are statistically significant (L.S.D.: $P < 0.001$; Statistica 5.0), ($n = 12$).

Nutrient content in pine fine roots

Carbon, nitrogen and phosphorus concentrations were analysed in pine fine roots ($\phi < 1 \text{ mm}$) (Table 2). The percentages of C and N in the roots from the Kampinos National Park and the Warsaw Steelworks were similar, however the concentration of $\text{PO}_4\text{-P}$ in pine roots from the control site doubled that from the polluted area. Table 2 presents also a higher N : P ratio in fine roots from the polluted than from the control site.

TABLE 2. Concentrations of carbon, nitrogen and phosphorus ($\text{PO}_4\text{-P}$) and the weight ratio N:P in fine roots ($\phi < 1 \text{ mm}$) of Scots pine from the Kampinos National Park (control site) and the Warsaw Steelworks (polluted site). Data are means $\pm$ standard deviation and represent root samples taken from 0-10 cm depth ($n=10$).

	Kampinos National Park	Warsaw Steelworks
$\text{PO}_4\text{-P}$ [%]	0.238 ± 0.020	0.143 ± 0.005
C [%]	32.2 ± 1.0	33.4 ± 1.0
N [%]	1.28 ± 0.06	1.34 ± 0.12
N : P	100 : 18.6	100 : 10.7

DISCUSSION

In this study the average activity of AcPase of Scots pine mycorrhizas was significantly lower at the site in the vicinity of the Warsaw Steelworks, polluted with sulphur and nitrogen oxides and heavy metals, when compared with the unpolluted forest site in the Kampinos National Park (Fig. 2). Similarly, a significant decrease of AcPase activity of Norway spruce ectomycorrhizas was reported by Rejšek (1991) at forest stands located in a coal-field in the Moravian-Silesian Beskid and influenced by high concentrations of air pollutants. These findings are in contrast to cytochemical observations of Turnau and Dexheimer (1995), who have shown, that the presence of cadmium dust increased the extracellular AcPase activity and the activity of this enzyme in the cytoplasm of mycelium of *Pisolithus arrhizus*, an ectomycorrhizal fungus resistant to toxic metals.

Several authors (i.e. Alexander and Hardy 1981; Kieliszewska-Rokicka 1992a; MacFall et al. 1991; Pasqualini et al. 1992) have shown that AcPase activities of ectomycorrhizal fine roots increase in response to limited availability of extractable Pi in the growth media. In this study, however, low concentration of inorganic P in the upper soil layer at the polluted site (almost three times lower than at the control plot) (Table 1), was accompanied by significantly lower activity of AcPase in soil and mycorrhizas (Figs 2, 4). The lack of clear response of mycorrhizal AcPase to Pi starvation, pointed out also by Bolan (1991) and Cumming (1996), may be a consequence of interspecific and intraspecific physiological variation of ectomycorrhizal fungi. Wide differences in AcPase activity and P allocation among isolates have been documented for different fungal species, such as *Pisolithus tinctorius* (Ho 1987; Cumming 1993, 1996), *Hebeloma cylindrosporum* (Meysselle et al. 1991), *Paxillus involutus* (Kieliszewska-Rokicka 1992b) and *Suillus luteus* (Kieliszewska-Rokicka et al. 1996). In the present study significant differences in AcPase were observed between mycorrhizal morphotypes of Scots pine (Fig. 2).

It is well known that development, maintaining and functioning of mycorrhizas depend on allocation of photosynthetic carbohydrates from shoot to root (Hampp and Schaeffer 1999). Scots pine trees at the polluted site in the vicinity of the Warsaw Steelworks had an increased concentration of heavy metals, sulphur and chloride in needles and anatomical changes in stems, such as decreased number of cambial cells and disturbance in differentiation of tracheids, when compared with Scots pine at the forest site in Kampinos National Park (Kurczyńska et al. 1997). These changes may decrease the rate of translocation of assimilates from shoot to root system and reduce the physiological activity of mycorrhizas.

The decreased activities of mycorrhizal and soil AcPases at the polluted site resulted both in low availability of Pi in soil

(Table 1) and relatively low content of phosphate in pine fine roots (Table 2). Elemental concentration in tree roots is considered a better phytoindicator of the nutritional conditions in the forest soil than foliar concentration (Joslin et al. 1988; Person and Majdi 1995). According to Ingestad (1979), the optimum weight proportion N : P for growth of Scots pine is 100 N : 15 P. In this study the root N : P ratio was optimal only in the unpolluted site (Table 2).

The upper soil layers of the study site near the Warsaw Steelworks were contaminated by high concentrations of metals such as Mn, Cd, Pb, Cr, Zn, Cu, Zn, Fe, especially in the extremely acidic A_{FEH} horizon (Material and Methods, Kurczyńska et al. 1993, 1997). Simultaneously, the concentrations of Mg²⁺, Na⁺ and Ca²⁺ were decreased at the polluted site (Material and Methods, Kurczyńska et al. 1993, 1997). Heavy metals may be toxic to soil microorganisms involved in decomposition of organic matter and nutrient cycling and inhibit the activity of soil enzymes (Zwoliński 1995; Kuperman and Carreiro 1997). Metals may also decrease the concentration of Pi in soil solution by immobilisation of phosphate ions in insoluble complexes in the soil substrate (Dalal 1977) and in phosphate-rich material accumulated in cell wall and within vacuoles of mycorrhizal fungi (Turnau et al. 1994). Some ectomycorrhizal fungi exhibit tolerance to high concentrations of the metals when grown in metal-polluted soil and are able to accumulate high amounts of certain metals (i. e. Gast et al. 1988; Turnau 1991). One of the mechanisms of defence strategy of ectomycorrhizal plants growing in polluted soils is immobilisation of toxic metals in phosphate-rich granular material observed within cells of ectomycorrhizal fungi (Leyval et al. 1997).

In the present study, the vitality of soil microorganisms, measured as the enzyme activity of non-specific dehydrogenase (DHA) did not differ between the study sites (Fig. 3). The decreased activity of the soil AcPase found at the contaminated site in the vicinity of Warsaw Steelworks (Fig. 4) suggest a toxic influence of heavy metals on the extracellular soil enzymes. These results are in an agreement with the results of Tyler (1974), who found a significant negative correlation between soil AcPase and sum of Cu and Zn concentrations in mor soil around a brass foundry in Sweden. Similarly, Juma and Tabatai (1977) showed inhibition of acid and alkaline phosphatases in soil by 20 trace elements in three different soils. They found a significant inhibition of the activity of soil acid phosphatase by Cu(II), Zn(II), Cr(II), Mn(II), Pb(II), Fe(III), Al (III) and they mentioned Cd(II) among the most effective inhibitors. The degree of this inhibition was dependent on soil properties and was the highest in sandy soil containing low level of organic matter. Similar soil conditions were observed at the experimental plot in vicinity of the Warsaw Steelworks (Material and Methods, Kurczyńska et al. 1993, 1997). The concentration of heavy metals (sum of seven elements: Pb, Cd, Mn, Cr, Zn, Cu, Fe) in the horizon A_{FE} near the Warsaw Steelworks exided 25 µmoles g⁻¹ of soil. Juma and Tabatabai (1977) observed that trace elements inhibited AcPase activity in the concentrations from 25 µmoles to 2.5 µmoles g⁻¹ of soil. In sandy soil Cu(II), Zn(II), Cr(II), Mn(II), Pb(II), Fe(III), and Cd(II) in concentration 25 µmoles g⁻¹ of soil reduced AcPase from 27 to 63 percent.

In conclusion, the results of this study indicated that low level of Pi in soil at the polluted site was accompanied by low activities of AcPases of ectomycorrhizas and soil and reduced concentration of phosphate in pine fine roots. Anthropogenic pollutants may exert a significant negative influence, directly or indirectly, on the enzyme activities. Differences in

AcPase activity among mycorrhizal morphotypes confirmed physiological variation between ectomycorrhizal fungi.

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STĘŻENIE FOSFORANU
ORAZ AKTYWNOŚĆ KWAŚNEJ FOSFATAZY GLEBY I EKTOMIKORYZ
DOROSŁYCH DRZEW SOSNY ZWYCZAJNEJ (*PINUS SYLVESTRIS* L.)
ROSNĄCYCH NA DWÓCH STANOWISKACH ZRÓŻNICOWANYCH
POD WZGLĘDEM POZIOMU ZANIECZYSZCZEŃ ANTROPOGENICZNYCH

STRESZCZENIE

Badano wpływ antropogenicznych zanieczyszczeń środowiska przyrodniczego oraz poziomu nieorganicznego fosforanu w glebie na aktywność enzymatyczną pozakomórkowej kwaśnej fosfatazy glebowej i powierzchniowej kwaśnej fosfatazy odciętych ektomikoryz 25-letnich drzew sosny zwyczajnej (*Pinus sylvestris* L.). Próby glebowe i korzeniowe pobierano w dwóch miejscach położonych w okolicy Warszawy: 1) w sąsiedztwie Huty Warszawa, na terenie zanieczyszczonym wieloletnimi emisjami pochodzącymi z huty oraz aglomeracji warszawskiej, 2) w Kampinoskim Parku Narodowym, na terenie wolnym od bezpośredniego wpływu zanieczyszczeń (kontrola). Gleba na terenie zanieczyszczonym zawierała pierwiastki śladowe (Cd, Pb, Cu, Zn, Mn, Cr) w stężeniach znacznie wyższych niż normalne i niski poziom nieorganicznego fosforanu. Żywotność mikroorganizmów glebowych była podobna na obu badanych stanowiskach. Natomiast na stanowisku zanieczyszczonym zarejestrowano znacząco niższą aktywność kwaśnej fosfatazy glebowej ($0,54 \mu\text{mola } p\text{-nitrofenolu g}^{-1}$ suchej masy) i powierzchniowej kwaśnej fosfatazy ektomikoryz sosny ($3,37 \mu\text{moli } p\text{-nitrofenolu g}^{-1}$ świeżej masy) niż na stanowisku odniesienia (odpowiednio, $1,36 \mu\text{moli } p\text{-nitrofenolu g}^{-1}$ suchej masy i $12,46 \mu\text{moli } p\text{-nitrofenolu g}^{-1}$ świeżej masy). Stężenie $\text{PO}_4\text{-P}$ w drobnych korzeniach sosen rosnących na terenie zanieczyszczonym było niższe od normalnego, natomiast stosunek N : P był wyższy od wartości uznawanych za normalne dla korzeni sosny w tej klasie wieku. Wyniki sugerują, że zanieczyszczenia powietrza oraz górnych warstw gleby stanowisku sosny zwyczajnej w sąsiedztwie huty mogą wpływać hamująco na aktywność kwaśnej fosfatazy gleby i ektomikoryz sosny oraz na zawartość fosforu w korzeniach drobnych.

SŁOWA KLUCZOWE: fosfor, fosfomonoesteraza, metale ciężkie, mikroorganizmy glebowe, zanieczyszczenia powietrza.