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Plant reactions as indicators of air pollution in the vicinity of a copper smelter

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Abstract

Several higher plant species and epiphytic lichen *Hypogymnia physodes* (L.) Nyl. were examined in the vicinity of a copper smelter. The investigations included field experiments. Ecological surveys of some biotests and bioreactions using exposure of higher plants and transplanted lichens were critically appraised. Such basic processes of plants as photosynthesis and respiration, as well as the quantitative composition of chlorophyll pigments were used as biotests. The results indicate that the photosynthesis intensity is the most useful measure for the estimation of the effect of both heavy metal and SO_2 pollutants. The degrees of chlorophyll degradation were in keeping with visual symptoms of injuries. For the ecological monitoring the measurement of respiration intensity, especially in lichens is not recommended. All applied biotests are presented in maps illustrating the degree of degradation of the area examined.

Key words: pollution ecology, lichens, photosynthesis, chlorophyll degradation

INTRODUCTION

Smelters have been recognized as important sources of air pollutants. The most toxic influence of air pollution on the vegetation results from sulphur dioxide and heavy metals emissions from smelters. Our examinations were carried out in the vicinity of the copper smelter "Legnica". The 25-year-long activity of this industrial plant has caused the cumulation of excess amounts of heavy metals (especially copper, lead, zinc) and sulphur dioxide in soil and vegetation. The degradation of the biological environ-

ment around the copper smelter is almost total. All attempts of restoration of the contaminated area through introduction of arborescent and herbaceous plants have failed. Therefore, it is necessary to estimate the intensity and range of the gaseous and dust pollution by means of biological monitoring. Pollutants can be detected in the environment and their influence on living organisms recorded using plant indicators. From among test plants which record pollution with e.g. sulphur dioxide, fluorine, heavy metals, lichens are undoubtedly the most frequently used (Gilbert 1973, Puckett 1976, Swieboda and Kalemba 1978, Bielecki and Fabiszewski 1979, Fabiszewski 1979, Nieboer and Richardson 1981, Richardson and Nieboer 1981). Special attention has been payed to the metabolic sensitivity of this group of plants, extremely sensible to pollution. As the measure of toxicant metabolic effect on lichens the intensity of basic physiological processes, e.g. photosynthesis and respiration, may be used (Baddaley et al. 1973, Puckett 1976, Ferry and Coppins 1979, Nieboer and Richardson 1981). The analyses of composition of chlorophyll pigments are equally important. The destructive influence of air pollution on chlorophylls has been found in lichens (Nieboer et al. 1976, Punz 1980) and in higher plants (Bell and Mudd 1976, Lauenroth and Dodd 1981). The divergence in test reactions of various species and in their metabolic sensitivity are crucial in evaluating the indicative value of particular phytotests in lichens and higher plants.

The carried-out studies concern the indicative value of various plant bioreactions in determining pollutant emission by the copper smelter. As indicators common crop plants and lichens were used, organisms known of their indicative and cumulative properties. The tests of plant reaction lay in photosynthesis and respiration intensity, as well as in the quantitative composition of chlorophyll pigments.

MATERIAL AND METHODS

In the vicinity of the copper smelter "Legnica" the method of transplantation of the epiphytic lichen *Hypogymnia physodes* (L.) Nyl. was used. The applied method was a modified version of the classic transplantation method of Brodo (1961) and Schönbeck (1969). The lichen was transplanted along two transects situated South-East and North-West of the emitor. As control, lichens transplanted into a non-polluted pine forest *Cladonio-Pinetum* were used, i.e. those transplanted in to the site from which they had been collected. After a two-months' exposition the lichens were examined on the intensity of photosynthesis and respiration, also on the content of chlorophylls and pheophytins in their thalli.

Close to the copper smelter (800 m) the effect of toxic emission on crop plants, grown in containers with unpolluted soil (natural brown soil from the Białowieża Primaeval Forest) was studied. The experiment was carried out on several species: horse bean (*Vicia faba minor*), blue lupine (*Lupinus angustifolius*), oat (*Avena sativa*) and red fescue (*Festuca rubra*). The plants were grown in a greenhouse through a period of two weeks after sowing and next exposed for a 2-weeks' period in the smelter area. The same species grown all the time in a greenhouse were regarded as a control treatment. The content of chlorophyll (chlorophyll a and b) was analysed as reaction test of the exposed plants. Measurements of photosynthesis and respiration intensity were carried out in a closed system by means a CO_2 analyser Infralyt III (Harris 1971). The chlorophyll pigment (higher plants and lichens) and pheophytin (lichens) contents were determined by means of a UV Vis "Specord" spectrophotometer after an appropriate preparation of the plant material. The data obtained were used to determine the pigment content by means of the relevant formulae (Fabiszewski et al. 1983).

RESULTS AND DISCUSSION

In higher plants exposed in the vicinity of the copper smelter a distinct inhibition in growth and development of the shoots — as compared with the control material — was noted. Toxicity symptoms caused by air pollutants appeared as visual injuries on leaves and stems. All plants showed acute chlorosis and reduction of the assimilation surface of their leaves. It is well known that leaves are the most sensitive organs to air pollution, among others because of the localization of the most important physiological processes in them (Guderian 1977). Moreover, younger leaves are generally known to be physiologically more active and more resistant to pollution than fully developed leaves (Guderian 1977). This was confirmed by the observations of plants exposed in the zone of copper smelter emission, where older leaves were effected first.

The chlorosis of leaves was the visual symptom of disturbed metabolism as effect of the copper smelter emission. In all exposed species the symptoms of acute chlorosis were correlated with a decrease in chlorophyll a and b content (Fig. 1). The content of chlorophyll a and b in leaves of contaminated plants and in control ones — differed significantly. Red fescue was found to be especially sensible. Its chlorophyll content decreased by a half as result of contamination. The drop in chlorophyll content in plants exposed for two weeks in the zone of intense pollution was probably caused by disturbances in the biosynthesis of chlorophyll pigments (Malhotra and Hocking 1976). The system of pigments in plants is very sensitive to SO_2

(Rabe and Kreeb 1980, Lauenroth and Dodd 1981), as well as to particular heavy metals (Cunningham et al. 1975, Rosen et al. 1977, Aro and Valanne 1978).

The investigations of lichens have shown that the measurements of photosynthesis intensity in order to evaluate the degree of environmental pollution around the copper smelter are the most efficient. This process characterizes by an intense sensitivity and precedes not only the visible damage of thalli

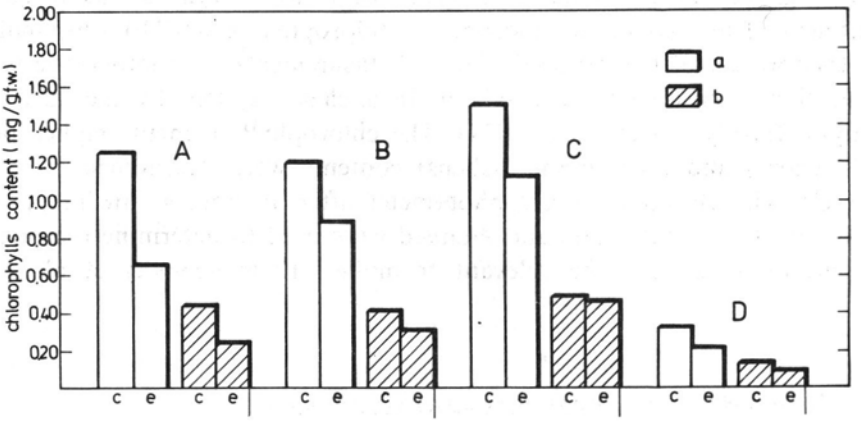

Fig. 1. Chlorophyll pigment contents in plant shoots exposed for two weeks in an unpolluted soil 800 m SE from the copper smelter. A — red fescue, B — oat, C — horse bean, D — blue lupine, a — chlorophyll a, b — chlorophyll b, c — greenhouse control plants, e — exposed plants

but also other metabolic changes (Baddaley et al. 1973, Ferry and Coppins 1979, Richardson and Nieboer 1981). The high sensitivity of photosynthesis, resulting in distinct changes in intensity of this process already at concentrations 0.05-0.2 ppm SO_2, persuades of the pertinence of applying this biotest as a method of the air pollution evaluation (Aro and Valanne 1978). Our results indicate that the intensity of photosynthesis is the most useful measure for the estimation of effects of both heavy metal and SO_2 pollutants (Fig. 2). From the presented diagram it may be inferred that the areas of highest pollution caused by the smelter were localized along the transection SE. The analyses of photosynthesis in the transplanted *Hypogymnia physodes* enabled to record the toxical influence of air pollution within a radius of as much as 10-15 km from the center of the emission. The determined range of activity of the copper smelter was found to be much larger than the area established according to visual injuries of *Hypogymnia physodes* thalli.

On the grounds of changes of photosynthesis intensity five zones of environmental contamination were determined: from the total inhibition of

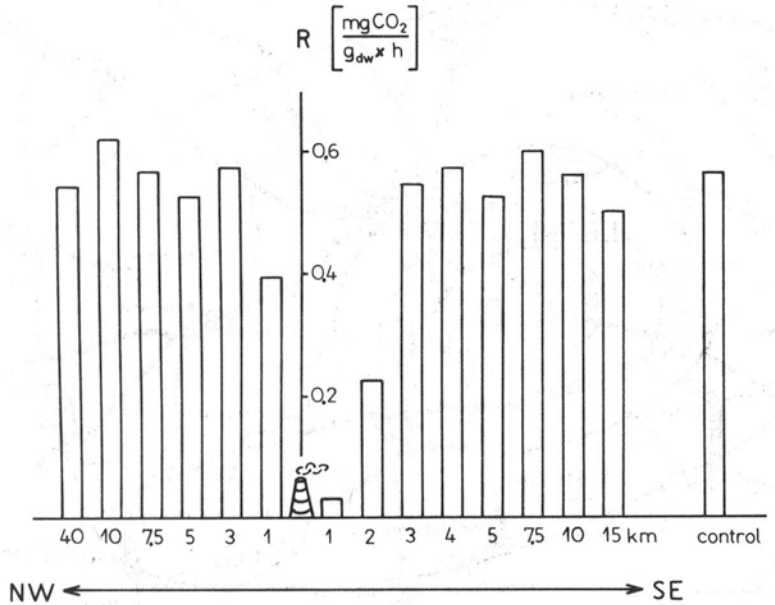

Fig. 2. Photosynthesis intensity (P) of *Hypogymnia physodes* exposed for two months along transects outwards the copper smelter

photosynthesis to 80% of the control value (Fig. 3). Their range was 13.7 km SE and 7.3 km NW.

The data on photosynthesis intensity of the transplanted *Hypogymnia physodes* were used for determination of the distribution of SO_2 emission in all the five zones around the smelter. For calculation the relevant formulae were used, based on the result of laboratory examination (Fabiszewski et al. 1983). The results obtained are presented as a map of air pollution in the area around the copper smelter (Fig. 4). The average two-months' concentration of SO_2 calculated on the basis of photosynthesis changes amounted from 0.4 mg m^{-3} in the area nearest to the plant to 0.025 mg m^{-3} 1.0-1.5 km away from it.

The content of chlorophyll and pheophytin in the thalli of the transplanted lichens can be regarded as an accessory biotest for estimation of air pollution (Figs. 5, 6). Quantitative changes in pigments (decrease in chlorophyll and increase in pheophytin contents) were found only in lichens with a photosynthesis intensity reduced to 60% of the control value. From the comparison of the content of pigments in thalli taken from various sites of the transects, presented in the map of SO_2 concentration, it can be concluded that quantitative changes in pigments appeared with a minimal SO_2 concentration of 0.05 mg m^{-3}.

The investigations of plant pigment systems are now recognized as almost

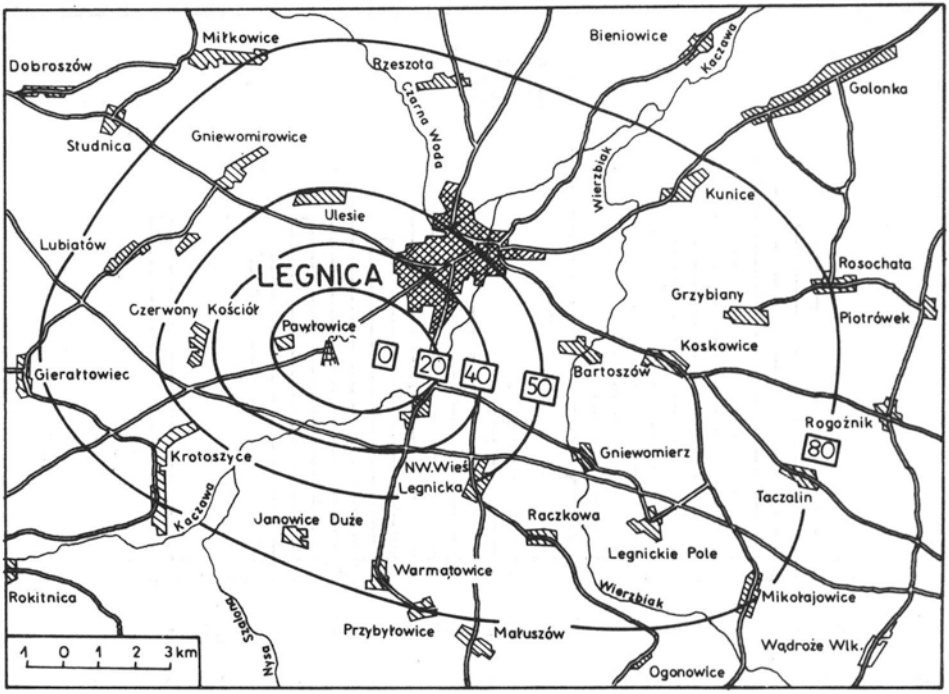

Fig. 3. Isolines of photosynthesis intensity (% of control) of *Hypogymnia physodes* transplanted for two months along transects outwards the copper smelter

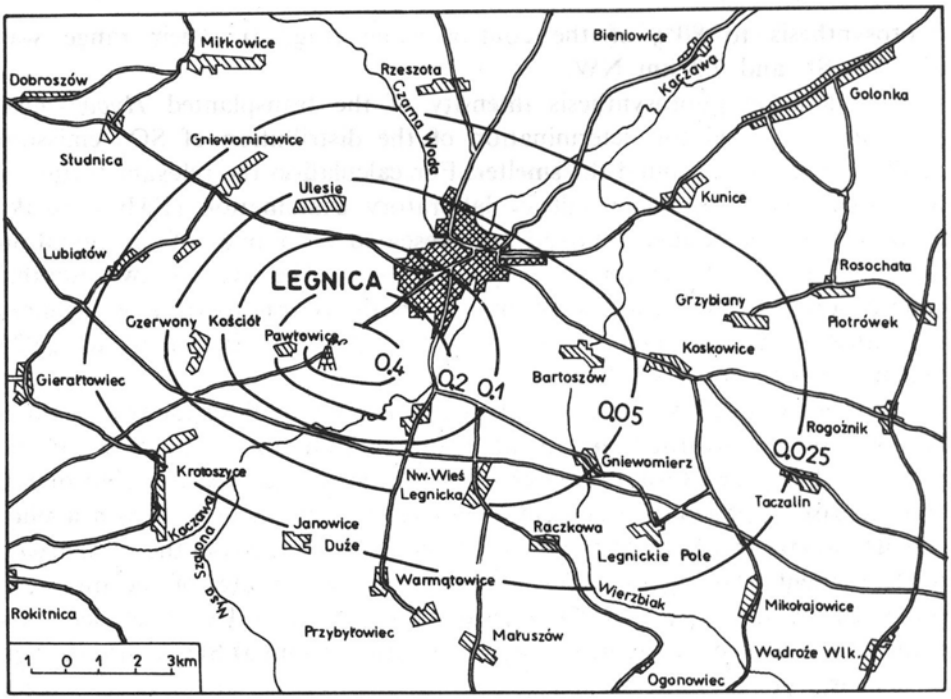

Fig. 4. Isolines of SO_2 concentration (mg·m ^{3}) in the vicinity of copper smelter calculated from the reduced photosynthesis intensity of transplanted *Hypogymnia physodes*

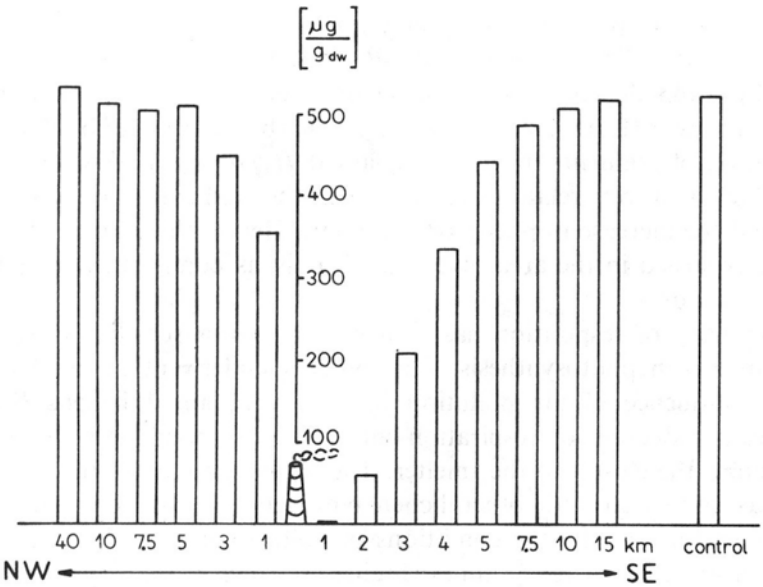

Fig. 5. Content of chlorophyll a and b in *Hypogymnia physodes* two-months-exposed along transects outwards the copper smelter

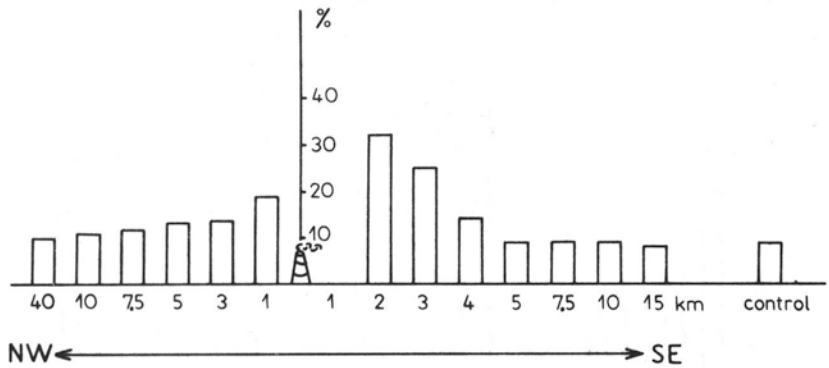

Fig. 6. Pheophytin content (% of total amount of pigments) in *Hypogymnia physodes* two-months-exposed along transects outwards the copper smelter

obligatory biological tests in polluted areas. It should be stressed, however, that the lower sensibility of chlorophyll pigments, as compared with photosynthesis, reacting is affected only by average and high pollutant concentrations (Puckett 1976, Rabe and Kreeb 1980). As a less common biotest the examination of pheophytins concentration is regarded. According to existing views, pheophytins are considered direct products of chlorophyll destruction under the influence of gaseous and dust toxicants. The results of recent investigations prove that chlorophyll pigments are predominantly oxidized,

and only a small part of them undergoes a conversion to pheophytins (Nieboer et al. 1976, Nieboer and Richardson 1981). The process of pheophytinization depends, at the same time, closely on the environmental reaction: a low pH increases it intensity (Rabe and Kreeb 1980). The determination of pigments in the transplanted *Hypogymnia physodes* confirm the lack of a direct relationship between the reduction of chlorophyll content and the increase in pheophytin content. Hence, these kinds of biotests should be regarded in the area investigated, only as complementary phytoindication methods.

The intensity of respiration has shown to be a less sensitive bioindicator as compared with photosynthesis. This process underwent minimal changes under the influence of air pollution in the transplanted lichens (Fig. 7). A significant reduction of respiration intensity was found only in the most polluted zone, the closest to the smelter. The higher stability of the respiration process, as compared with other lichen bioreactions, was confirmed in the relevant literature. Under the conditions of polluted environment, respiration can demonstrate a 3 to 5 times higher resistance than photosynthesis (Baddaley et al. 1973).

The usefulness of the suggested methods of phytoindication is well illustrated in Fig. 8. It presents a comparison of ranges of pollution zones determined by means of various biotests in result of a two-months'

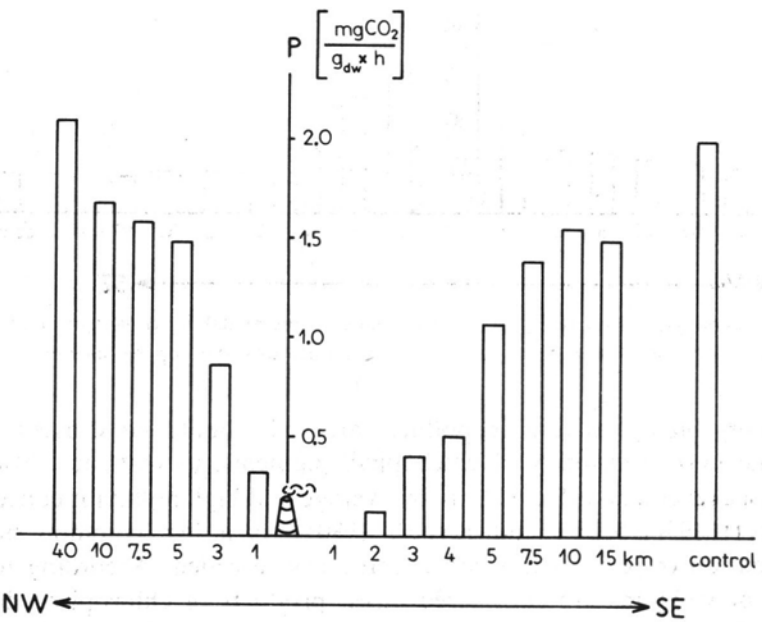

Fig. 7. Respiration intensity (R) of *Hypogymnia physodes* two-months-exposed along transects outwards the copper smelter

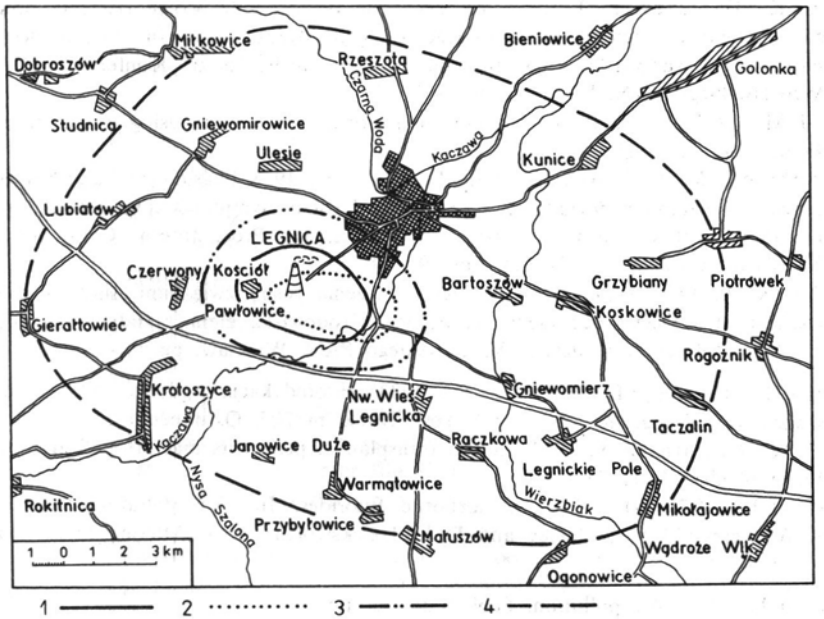

Fig. 8. Comparison of range of pollution zones determined by different biotests after two months exposition of *Hypogymnia physodes*. 1 — intensity of respiration, 2 — pheophytin content, 3 — chlorophyll content, 4 — intensity of photosynthesis. Isolines of photosynthesis, respiration and chlorophyll show the range 0-80% control value, while isoline pheophytin indicates an area of concentration up 20% pheophytin content compared with the total pigment amounts

long transplantation of *Hypogymnia physodes*. The zone demarcated by measurements of photosynthesis intensity has the greatest range. The process of photosynthesis has a high sensitivity, hence it is a good test to copper smelter pollutants. The pigment system of the lichens under study was found to be less responsive to air pollution. We cannot, however recommend the use of respiration intensity measurements in lichens as a method of indication in an area similar to that discussed above in respect of type and magnitude of pollution in account of the increased resistance of this process.

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Testy roślinne jako wskaźnik skażenia atmosfery wokół huty miedzi

Streszczenie

Celem badań było porównanie wskaźnikowego znaczenia niektórych bioreakcji roślin w wyznaczaniu zasięgu i rozmiaru odddziaływania metali ciężkich i SO_2, emitowanych z huty miedzi. Za rośliny wskaźnikowe posłużyły: nadrzewny porost *Hypogymnia physodes* (L.) Nyl. oraz pospolite gatunki uprawne (*Vicia faba minor*, *Lupinus angustifolius*, *Avena sativa* i *Festuca rubra*). Testami reakcji roślin były: intensywność fotosyntezy, oddychania oraz ilościowy skład barwników chlorofilowych. Zebrany w terenie nieskażonym porost *H. physodes* transplantowano w różnych odległościach od huty wzdłuż wyznaczonego transektu. Po dwumiesięcznej ekspozycji w plechach porostów mierzono natężenie fotosyntezy i oddychania, zawartość barwników chlorofilowych i feofityn. W bliskim sąsiedztwie huty przeprowadzono eksperyment typu fitometrycznego z ekspozycją roślin wskaźnikowych, trwającą dwa tygodnie. W eksponowanych roślinach badano zawartość chlorofilu a i b. Intensywność fotosyntezy transplantowanego porostu była najbardziej przydatnym wskaźnikiem skażenia środowiska wokół huty. Mniej wrażliwy na emisje metali ciężkich i SO_2 okazał się system barwnikowy testowanych roślin. Z uwagi na stwierdzony brak zaburzeń w oddychaniu u transplantowanych porostów pomiar tego procesu nie może spełniać roli indykacyjnej.