Bulg. J. Plant Physiol., 1996, 22(1–2), 53–63

EFFECT OF AIR POLLUTION ON CARBOHYDRATE AND NUTRIENTS CONCENTRATIONS IN SOME DECIDUOUS TREE SPECIES

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Received January 15, 1996

Summary. The concentrations of sugars, starch, nutrients and some heavy metals were examined during the growing season in four tree species (*Ailanthus glandulosa* DESF., *Carpinus betulus* L., *Tilia argentea* DESF. and *Quercus cerris* L.), growing in natural and planted stands in a region with considerable industrial emissions and in an unpolluted area.

Trees in the polluted regions had lower concentrations of starch, total and soluble sugars than trees in the unpolluted regions. A high accumulation of heavy metals (better expressed at the end of the growing season) was recorded. The changes in the concentrations of nutrients in leaves were specific in the tree species studied.

A comparison of the four tree species indicated that *Q. cerris* was the most tolerant to air pollution.

Key words**:** air pollution, phytotoxic agent, carbohydrates, heavy metals, nutrients

Introduction

Atmospheric pollutants, especially oxidants, phytotoxic metals and acid deposition cause stress in forest trees. Vast areas of deciduous forests have been damaged in Eastern Bulgaria during the past decades. Because there are large amounts of gas and dust air pollution resulting from many different sources, it is difficult to attribute the forest decline to a single causal factor (Iotsova-Baurenska et al., 1985; Gateva, 1994;

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Malinova, 1994). It has been suggested that the recent decreases in forest tree growth rate were caused by a combination of stress factors (i.e. drought, pathogens, anthropogenic pollutants). The tolerance of particular tree species to industrial phytotoxic agents varies widely. Air pollutants directly affect the net carbon dioxide exchange rate and dry matter accumulation of many forest tree species (Miller et al., 1969; Mudd and Kozlowski, 1975; Malhorta, 1976; Carson, 1979; Lorenc-Plucinska, 1982a,b). Data about the biochemical mechanisms and role of nutrients in the susceptibility of trees to toxicants are limited too (Wilkinson and Barnes, 1973; Kazmierczakowa, 1975; McLaughlin, 1986; Mankowska and Ostrolucka, 1986; Konecna et al., 1989; Masarovichova, 1989). There are also few data on the influence of air pollutants on carbohydrate metabolism (Dugger et al., 1966; Miller et al., 1969; Barnes, 1972; Malhorta and Sarkar, 1979; Youngner and Nudge, 1980; Lorenc-Plucinska, 1982a).

The aim of this investigation is to determine the effect of industrial emissions on the levels of total and soluble sugars, nutrients and some heavy metals in the adult leaves of four deciduous tree species and to assess the role of these parameters as markers for plant damage.

Materials and Methods

Site description

The investigation was carried out in damaged forests (situated in the industrial region of Devnia lowland at about 2000 m on the north of Nitrogen Fertilizers Factory) and in control forests from a relatively unpolluted region. The forests studied in two regions consisted of 30–40-year-old natural sprigging stands of *Quercus cerris* L. – 1513.9 ha and *Carpinus betulus* L. – 11330 ha as well as of 16-year-old silviculture of *Tilia argentea* DESF. and *Ailanthus glandulosa* DESF. – 1603.8 ha.

The climate in this lowland is continental, but is influenced by the Black Sea. The mean annual air temperature was about 12.0–12.7 °C, and about 21°C – for the growing season. The average annual precipitation was about 500 mm (200–250 mm for the growing season), with a spring-summer maximum. Prolonged summer droughts are typical. The prevailing winds are with an eastern and western components. The breeze circulation has been registrated in 15–19 days per annum (Raev et al., 1982).

Air pollution

The main toxicants in the industrial region of Devnia lowland are: nitrogen oxides (NO, NO_2), sulphur dioxide (the basal toxic agent in the emission with mean content – 11.18 $mg.m^{-2}$ SO_2 per 24 hrs), carbon oxides, HF, NH_3, Cl, HCl, CaO, $CaCO_3$, solid or liquid aerosols and organic compounds, higher amounts of silicon, aluminium, sodium, iron, cadmium, and lower concentration of magnesium, calcium, nickel, lead, copper, zinc, manganese, as well as dust and soot. To this add the dust and gases from more distant industrial establishments, from the city and from motor vehicles. Most nitrogen oxides in the atmosphere are converted to nitric acid, which, when dissolved in droplets, contributes to the acidification of cloud and rain water. The same holds true for sulphur dioxide and other sulphur-containing trace gases.

Soil conditions

Polluted region. With a south exposure and humus-carbonate soil, rich of humus, well supplied with total nitrogen and potassium (39–67 mg/100g), and with a low content of phosphorus (pH > 6.3). Almost neutral soil reaction in the polluted regions favourable magnesium exchange. The concentration of total magnesium is higher (286.0–316.5 mg/100 g) than that of total calcium (85–180 mg/100 g), due to heavy mechanical composition of the soil and leaching of calcium during the forest soil-forming precesses. The amounts of industrial aerosols accepted are about 256.31 kg/dka per annum. The soil contamination resulted in the changes of chemical composition within the surface soil layers of macro- and micronutrients. An accumulation of cobalt, manganese, iron, copper and nickel was established. The scale of heavy metals was: Co > Cu > Pb > Ni (Zeliazkov and Peev, 1984).

Unpolluted region. Dark gray-brown forest soils and sandy-loam in the *Q. cerris* stand. The soil is rich in humus, well supplied with available potassium (30–75 mg/100 g) and magnesium, relatively slightly supplied with total and available nitrogen and phosphorus (pH = 8.3–7.1). This region is situated on the south of the industrial lowland and is well preserved from blowing dust and aerosols because eastern winds prevail during the growing season. The deposition of industrial toxic agents was from 4 to 5 times lower. The preserved forest stand is favourable for the dynamics of the microelements and detoxication of the soil substratum (Zeliazkov and Peev, 1984).

Biochemical analysis

Ten similarly aged trees of each species were sampled from damaged and control stands. Adult leaves were collected from the middle south parts of each tree crown in the late mornings of sunny days in June and September 1988 and 1989. The leaves were analysed after mechanical cleaning of the leaf blades. Contents of water soluble sugars, total sugars and starch were determined by the anthron method (Hansen and Moller, 1975). Absorption was measured at 620 nm with a PERKIN-ELMER Lambda 2 UV/VIS spectrophotometer.

After digesting leaf powder in sulphuric acid and hydrogen peroxide total nitrogen concentration was determined by the Kjeldahl procedure. Total phosphorus was analyzed colorimetrically by molybdophosphoric blue reaction.

Subsamples of the ground tissue were combusted in a muffle furnace at 470 °C and dissolved in concentrated HNO_3 and $HClO_4$. The solutions were analyzed for potassium, calcium, magnesium, manganese, iron, copper, and zinc on PERKIN-ELMER 370A atomic absorption spectrophotometer.

At least three readings of samples were taken, each sample was replicated twice and the entire experiment was repeated once.

The results were analyzed statistically by using the standard t-test in order to determine the significant differences between damaged and control stands.

Resuts and Discussion

Concentrations of total, soluble sugars and starch decreased significantly in the trees from the polluted regions. On most occasions, the leaves were more susceptible to air toxicants, in relation to the carbohydrate content, in June ($P \leq 0.05$) than in September (Fig. 1). In damaged *Q. cerris* leaves the decrease in concentrations of sugars was higher in September. In damaged leaves of *T. argentea* from the polluted regions higher accumulation of sugars and starch was found in September.

There were well pronounced differences among the four tree species with respect to their reaction to phytotoxicants. *A. glandulosa* showed the highest susceptibility, followed by *C. betulus*. *Q. cerris* had a low susceptibility in June compared to the other three species, but was more sensitive in September.

The decrease in total sugar content of damaged leaves probably corresponded with the photosynthetic inhibition or stimulation of respiration rate. Higher starch accumulation in damaged leaves of *T. argentea* and *Q. cerris* maybe resulted both in the higher resistance of their photosynthetic apparatus (Prokopiev, 1978) and low starch export from the mesophyll. The negative effect of heavy metals on carbon metabolism is a result from their possible interaction with the reactive centre of ribulose-bisphosphate carboxilase (Stiborova et al., 1987). Significant changes in the morphology and the functional activity of the nucleus have been observed (Doncheva, 1992; Doncheva et al., 1993, 1996). A higher inhibition of photosynthesis and photorespiration in the less resistant individuals were established in *P. sylvestris* by Lorenc-Plucinska (1982a). Immediately following ozone exposure, soluble sugars in pine needles decreased (Wilkinson and Barnes, 1973). Subsequently they increased, frequently in association with foliar injury (Dugger et al., 1966; Miller et al., 1969; Barnes, 1972). Acute exposure to oxidants reduced starch content (Ziegler, 1975; Yougner and Nudge, 1980). The increase of soluble sugars was also observed following chronic exposure (Miller et al., 1969). The highest accumulation of carbohydrates as reserve compounds was established in soils, well supplied with nitrogen (Guderian et al., 1985). As far as the sensitivity to the toxic effect of air pollution was in a positive correlation with the photosynthetic rate (Lorenc-Plucinska,1982a,b), our data were not in

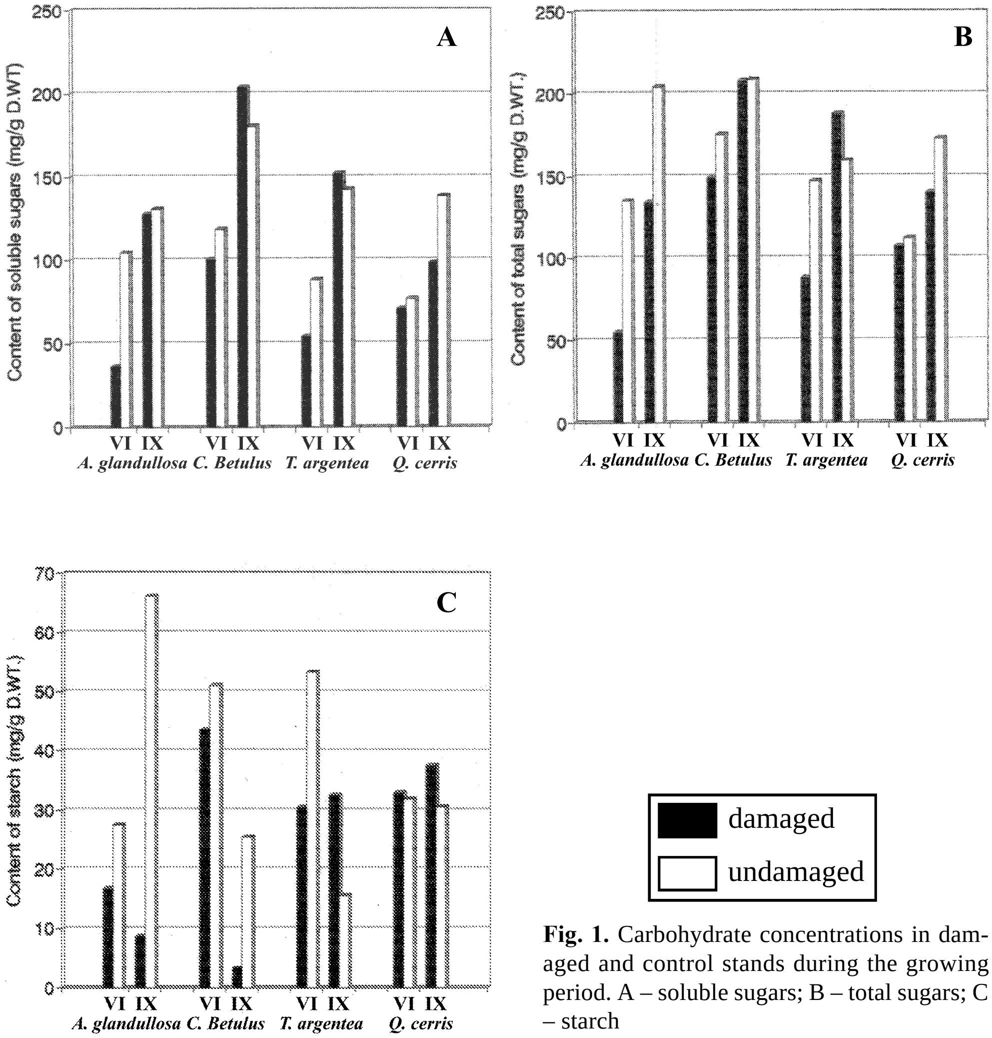

Fig. 1. Carbohydrate concentrations in damaged and control stands during the growing period. A – soluble sugars; B – total sugars; C – starch

agreement with the investigation of Marek et al. (1989), which established a higher rate of photosynthesis at *Q. cerris,* compared to *C. betulus*. At the same time, on the basis of the ribulose-bisphosphate carboxilase activity, Konecna et al. (1989) estimate *Q. cerris* as an oak species resistant to air pollution.

In most tree species investigated damaged leaves had higher amounts of total nitrogen, phosphorus and potassium ($P \leq 0.05$) (Fig. 2). Nitrogen concentration was higher in June than in September both in damaged and control stands. The largest differences between damaged and control plants in the content of total nitrogen were found in leaves of *A. glandulosa* in September. Higher total nitrogen concentration

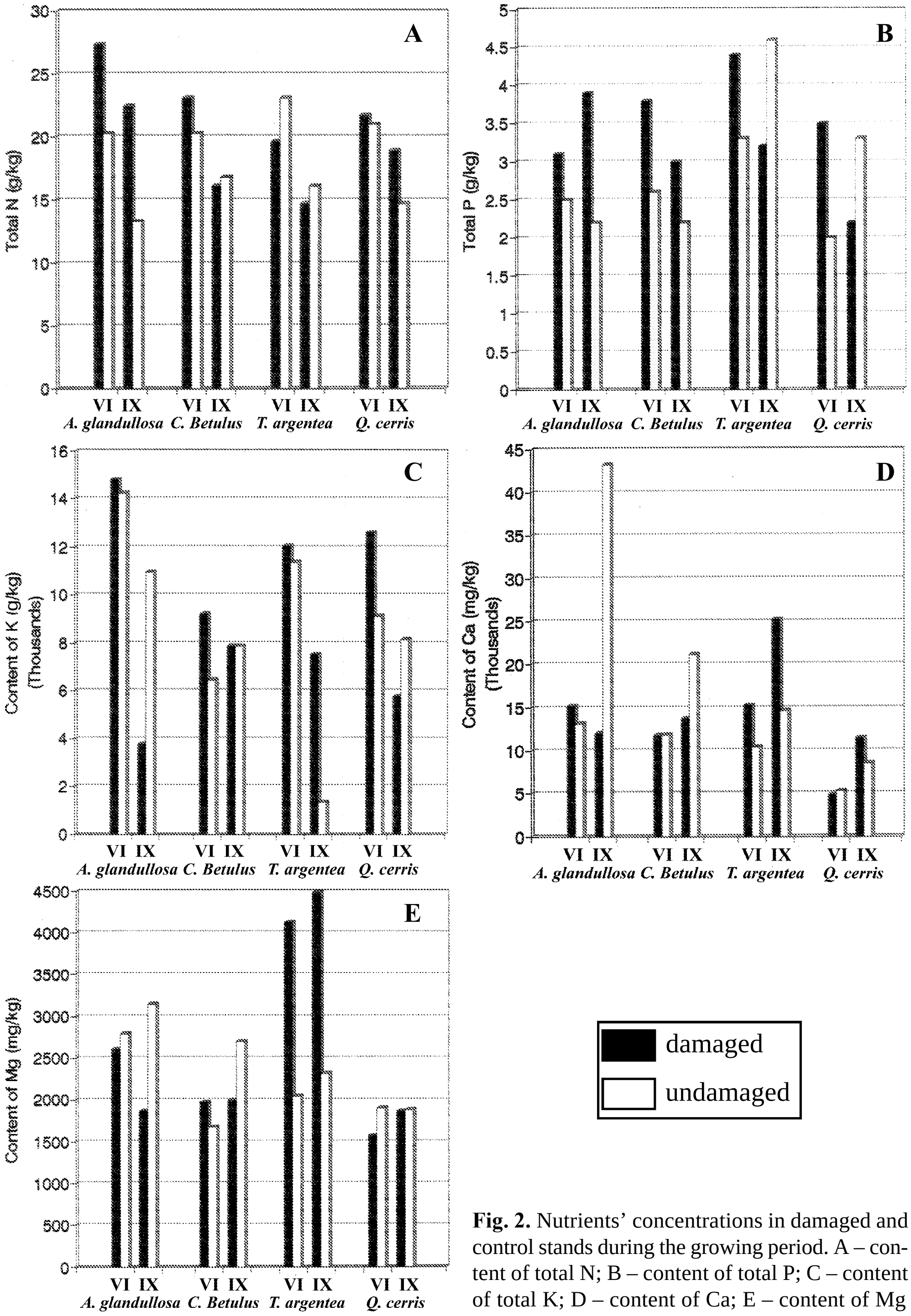

Fig. 2. Nutrients' concentrations in damaged and control stands during the growing period. A – content of total N; B – content of total P; C – content of total K; D – content of Ca; E – content of Mg

in damaged leaves mainly was due to the existence of N-oxides in the industrial emissions. N-oxides concentration is the most important factor for leaf absorbtion of these compounds (Doncheva-Boneva, 1991). The soils in the polluted region were also well supplied with total nitrogen (Zeliaskov and Peev, 1984). Higher phosphorus concentration in damaged foliage – especially in June – may be explained with the higher soil moisture. High soil acidity in the polluted region was favourable for phosphorus availability. This element is well exchangable and its leaf concentration is connected with the high physiological activity in the beginning of the growing period. The accumulation of total phosphorus in damaged leaves was associated with the higher energetic expenditure for the adaptive processes. Higher respiration rate was established in tree species resistant to air pollution (Lorenc-Plucinska, 1982a). Largest amount of phosphorus was recorded in the injured leaves of *T. argentea*. The soils both in polluted and control regions were well supplied with potassium. The higher concentration of potassium in damaged leaves of all tree species investigated was associated with heavy mechanical composition of the polluted soils, determining relatively higher part of soluble nitrogen. Lower concentration of calcium in these soils was favourable for potassium uptake. The highest potassium level was found in damaged leaves of *A. glandulosa* in June. This element takes part in membrane permeability and stomata action (Raschke, 1975). Potassium has an effect on the adaptive processes by its action on the hydration of the tissues and on some enzyme activity of the carbon metabolism. High potassium concentration and low calcium level in the leaves of *Q. cerris* from polluted regions have also been found by other authors (Konecna et al., 1989). The decreased level of nitrogen, phosphorus and potassium in September was a result of their export to the stem, low uptake and second including in the metabolic cycles. High soil acidity is connected with intensive leaching of the nutrients from the leaves (Materna, 1984). Lower nutrients level has been established as a cause of physiological injuries (Guderian, 1977). Higher decrease in concentrations of potassium, calcium and magnesium have been found in more susceptible species (*A. glandulosa* and *C. betulus*).

Concentrations of calcium and magnesium were higher both in July and in September in damaged leaves of *T. argentea* ($P \leq 0.05$ and $P \leq 0.01$) (Fig. 2). The amount of calcium in the leaves both in polluted and control stands was higher in the end of the vegetative period because of its low mobility.The highest amount of calcium was observed in damaged *A. glandulosa* in June. Lower soil supply with calcium in the industrial region probably was partly compensated by the higher soil humidity, which was favourable for calcium uptake. A great magnesium deficiency was found in the leaves of *A. glandulosa* ($P \leq 0.001$) and *C. betulus* ($P \leq 0.01$). The higher magnesium level in the leaves of *T. argentea* ($P \leq 0.001$) corresponded with increased exchange of magnesium in acid soil. The higher level of magnesium in the leaves has a protective effect (Moot and Berry, 1968). Higher resistance of *Q. cerris* could result from the protective action of magnesium regardless of low leaf calcium concentration. Because of the low calcium level its antagonistic effect on magnesium uptake did not occur and plants had more favourable nutrient conditions (Zeliaskov and Peev, 1984). The differences between concentrations of these two elements in damaged and control leaves increased in September. The same tendency has been observed by other authors (Evers, 1982). It is connected with increased membrane permeability and low soil humidity. At that time the negative effect of air pollution increased too.

A certain degree of selectivity was observable in the accumulation of individual metals by the species (Fig. 3). Concentrations of manganese, iron and zinc were sig-

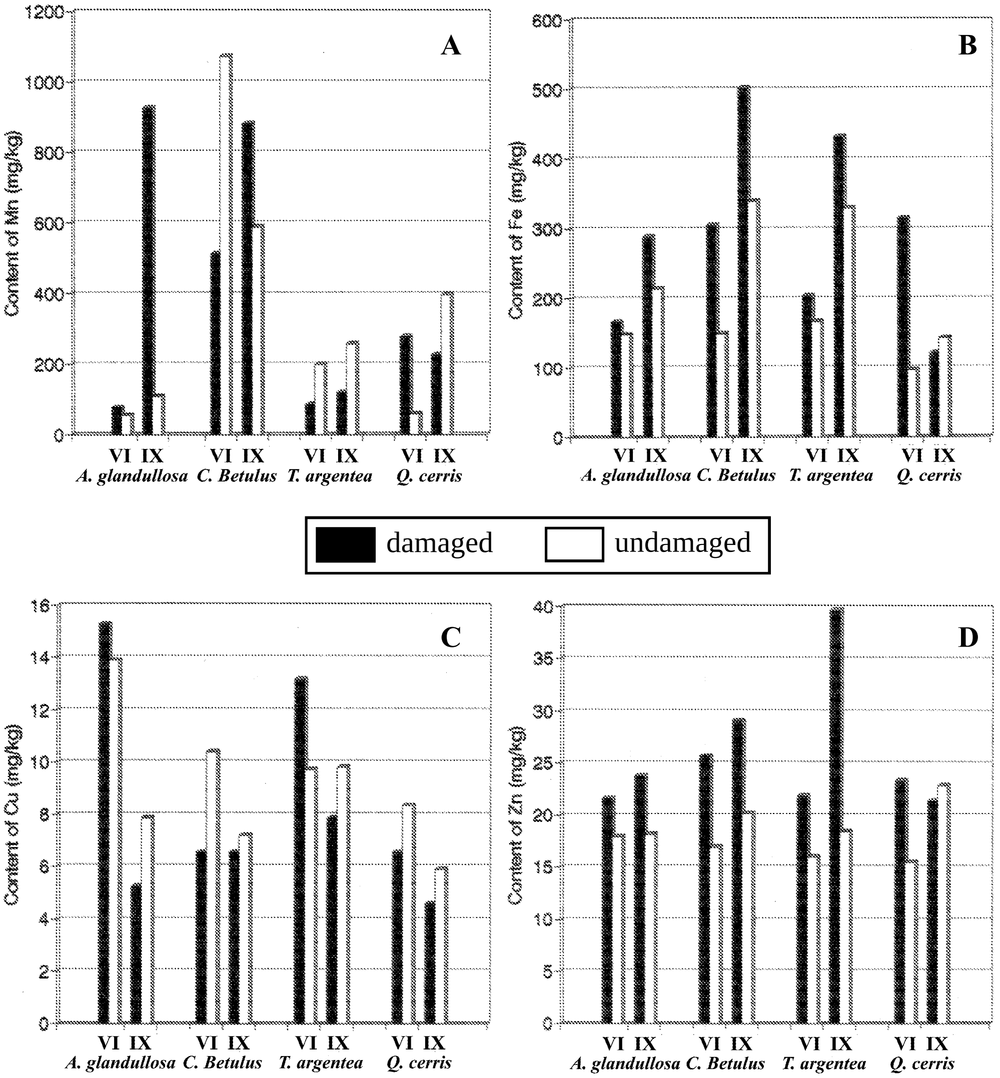

Fig. 3. Microelements' concentrations in damaged and control stands during the growing period. A – content of Mn; B – content of Fe; C – content of Cu; D – content of Zn

nificantly greater in most tree species from polluted regions. Because of higher soil acidity there were greater amounts of soluble manganese, which was favourable for iron availability. Lower acidity of the soil in the control stands caused mainly Mn^{2+} precipitation and low concentration of soluble copper. Despite of its greater mobility in acid soil copper was not taken up intensively by damaged trees. Copper was accumulated mostly in polluted leaves of *T. argentea. A. glandulosa* accumulated large quantities of manganese, but only small amounts of zinc. Leaves of *C. betulus* preferentially accumulated iron. *T. argentea* showed higher degree of zinc accumulation. The most pronounced differences between damaged and control plants were found in the manganese concentrations of the leaves of *A. glandulosa* ($P \leq 0.001$), and in the copper and zinc concentrations of the leaves of *C. betulus* ($P \leq 0.01$) and *Q.cerris* ($P \leq 0.001$). Comparative analysis of metal accumulation established that most of the species examined accumulated mainly zinc and iron. It was found that in response to air pollution, the more resistant plants accumulated greater amounts of toxic elements (Kazmieczakowa, 1975). According to our results, polluted *Q. cerris* leaves accumulated more manganese, iron, and zinc, but in the same time showed small changes in carbohydrate concentration.

Conclusion

Among the species analyzed, *T. argentea* and *A. glandulosa* may be good bioindicators.

In relation to carbohydrate complex *Q. cerris* showed the highest resistance to industrial emissions of the four species examined. This tree species could be recommended for afforestation of industrial regions.

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