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INFLUENCE OF URBAN AGGLOMERATION ENVIRONMENTAL POLLUTION ON CONTENT OF CHOSEN METALS IN BARK, ROOTS AND WOOD OF NORWAY MAPLE (*ACER PLATANOIDES* L.)

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ABSTRACT

Chosen metals contents were analyzed in Norway maple (*Acer platanoides* L.) in bark, roots and wood samples collected from the polluted environment. Samples were gained from three cca. 40-year old trunks, which were grown on Krakowskie Przedmieście st., next to the St. Anna church in Warsaw, Poland. Wood of trunk and the main roots, as well as bark from butt-end section were also sampled.

Contents of Ca, Mg, Mn, Zn, Fe, Al, K, Na and Sr were examined with the application of spectrometric methods. The results show that environmental pollution significantly influences the content of examined elements. The change of Na content is the most spectacular. Its content is hundred times higher, in wood and bark, as well as in the main roots, in relation tree from non-polluted environment, what is probably caused by urban environment salinity.

KEYWORDS: Norway maple, wood, roots, bark, metals.

INTRODUCTION

Susceptibility of plants, including trees, to the action of substances causing the environmental pollution, as well as the range of resulting damages depend on both biotic and abiotic factors (Kopcewicz et al. 1998). Substances, which, being present in the air, may harmfully affect plants and animals, are acknowledged as environmental pollutants. They are divided into solids (dusts and soots), liquids (fumes) and gases. Harmful action of dusts depends on the level of fall, degree of fragmentation, chemical composition and their solubility in water. The unfavorable effect raises with the degree of fragmentation. The change of soil reaction may take place as the result of the deposition of high amount of dusts. This may lead to impediment of nutrients collection by trees, especially phosphorus, potassium and nitrogen and microelements (Kopcewicz et al. 1998).

Soot may affect trees both in physical and chemical way. Soot and dusts deposing on leaves plug the respiratory apparatus and impede the penetration of sunlight into chloroplasts. Inadequate functioning of the respiratory and assimilation apparatus causes the disorder of gaseous exchange and plant nutrition what decreases their vitality.

Sulfur dioxide, nitrogen oxides and hydrohalogenes are the most harmful air pollutants for plants.

Dependent on factors causing environmental pollution, different changes in the content and distribution of macro-, micro- and trace elements (including heavy metals) take place. It may occur regardless the tree species, both on the cross- and longitudinal section of trunks (Krutul 1996, Krutul and Sacharczuk 1997, Krutul et al. 1999, Krutul and Makowski 2004, 2005).

Bark is the differentiate tissue formed by phellogen, covering the trunk and tree branches. As the external factors affect it directly, some elements might penetrate to wood through the bark (Watmough 1997). Rademacher et al. (1986) stated that spruce (*Picea abies* L.) bark collected from trees grown in the environment with very high pollution degree contains cca. 1.5% more potassium (K) and 7.5% more calcium (Ca) in relation to bark gained from tree grown in the environment with lower degree of pollution. High pollution degree causes also the decrease of the content of magnesium (Mg) and aluminum (Al), but the increase of manganese (Mn), iron (Fe) and zinc (Zn) contents both in bark and wood (Rademacher et al. 1986).

According to Krutul and Makowski (2005), bark and wood of Norway maple (*Acer platanoides*) collected from tree grown in the other area of Warsaw, Poland, on the corner of Marszałkowska and Świętokrzyska st., contain more calcium, potassium and magnesium, but firs of all more chlorine (Cl) and sodium (Na), in relation to bark and wood from unpolluted environment. Content of lead (Pb), strontium (Sr), iron and aluminum in bark is higher in relation to wood.

Wood from roots contains more calcium, iron, manganese, zinc and aluminum, but less potassium and magnesium in relation to wood from trunk pith adjacent-, middle- and outer zone (Krutul and Makowski 2005).

Different changes in particular elements contents on the cross- and longitudinal sections are dependent on the environmental pollution degree.

Following factors are the main sources of the environmental pollution in Warsaw: the industry, transport and salinity as the result of the application of salt to defrost the sidewalks and streets.

That is why the studies were performed of the influence of urban environment on the content and distribution of particular metallic elements in bark and wood of the main roots and trunk of Norway maple.

MATERIALS AND METHODS

Samples were collected from cca. 40-year old Norway maple (*Acer platanoides* L.) Tree was grown near the Krakowskie Przedmieście street, next to the saint Anna church in Warsaw. Disks of 200 mm height were cut in butt-end and middle trunk part, as well as 100 mm height from the top part. Main roots were also sampled. On the cross-section of butt-end disk following sections were distinguished: pith adjacent-, middle-, outer wood, in the disk from middle part:

pith adjacent- and outer wood. Disk from the top part was not divided because of small diameter.

Samples were gained from each zone all around the trunk cross-section using drill. Obtained samples were fractionated. Mineral substances were determined in muffle furnace at the temperature of 600°C, until the constant mass was reached.

Content of particular elements in wood, bark and roots was analyzed according to following procedure: known mass of absolute dry ash obtained after burning of 2.5 g of dusty fraction was placed in the measuring flask (50 cm^3). Then 5 cm^3 of 10% hydrochloric acid was added and flask was filled with distilled water.

The technique of emission atomic spectrometry with inducted plasma ICP-AES was applied to determine calcium (Ca), magnesium (Mg), manganese (Mn), iron (Fe), zinc (Zn), aluminum (Al), strontium (Sr) content. The technique of flame atomic absorption spectrometry (FAAS) was applied to determine potassium (K) and sodium (Na) content.

RESULTS AND DISCUSSION

Physiological functions of macro- and microelements in plants are differentiate. These elements are the components of particular organic compounds being a content of cell structures, including many enzymes and coenzymes. Calcium, potassium, magnesium belongs to the group of metallic elements acknowledged as macroelements (Kopcewicz et al. 1998).

Calcium is the element collected by plants from the soil when the pH is low, in the soluble form of Ca^{2+}. That is why the total content of this element in soil does not correspond to the capabilities of its collection by plant (Kopcewicz et al. 1998).

On the basis of data presented in the Fig. 1 it may be stated that calcium content on the butt-end cross-section in pith adjacent wood is fivefold higher in relation to outer wood and sevenfold higher in comparison to middle wood. Also in the cross-section from the middle trunk height pith adjacent wood contains higher amount (six fold) of calcium than outer wood.

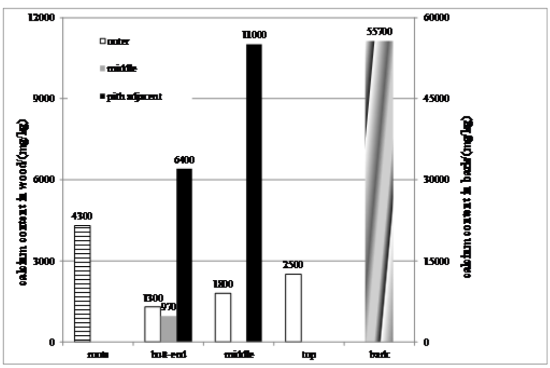

Fig. 1: Calcium content in analyzed wood and bark.

Calcium content in the top trunk part is twice and twentyfold higher in relation to, correspondingly, pith adjacent and middle wood from butt-end section. On the other hand, this content is four times lower in comparison to pith adjacent wood from the middle trunk part, and one and a half times higher in relation to outer wood from the middle section.

Results obtained for butt-end section are similar to those obtained by Krutul and Makowski (2005) for wood of Norway maple, gained also from polluted environment of Warsaw agglomeration. According to these results, pith adjacent wood contains threefold higher calcium amount than middle and outer wood.

Data is also compatible with the results of Watmough et al. (1998). Authors denoted that calcium content on the sugar maple (*Acer saccharum*) decreases in the direction from pith to perimeter.

Wood from the main roots contains higher amount of calcium in relation to wood from the top part and butt-end sections (all zones) and outer wood from the middle trunk height. Content of calcium in roots is one and a half lower in comparison to pith adjacent wood from the middle section of the trunk (Fig. 1).

Calcium content in roots is cca. 40% lower in relation to roots analyzed by Krutul and Makowski (2005) in Norway maple trunk gained from Warsaw agglomeration.

Bark contains dozens of times higher amount of calcium than outer wood, thirteen times higher than main roots and fivefold higher than pith adjacent wood (Fig. 1). Obtained data is consistent with calcium content in bark from butt-end section of Norway maple trunk gained from Warsaw agglomeration area, which was denoted by Krutul and Makowski (2005). Obtained results are also in accordance with the data of Krutul and Sacharczuk (1997) which showed that oak bark contains over forty fold more calcium than wood.

According to Rademacher et al. (1986), calcium content in spruce (*Picea abies*) bark taken from significantly polluted environment is cca. 7.5% higher in relation to samples from middle and low polluted areas.

On the basis of obtained results it may be stated that environmental pollution influences the distribution and content of calcium in wood of Norway maple, on the cross- and longitudinal section of the trunk, as well as its content in bark.

Potassium is the element necessary for proper plant development. It is collected by roots system in the form of K+.

On the basis of data presented in the Fig. 2 it may be stated that potassium content in pith adjacent wood from butt-end section is cca. 14 % higher in relation to outer wood and cca. 40% higher in comparisonto middle wood.

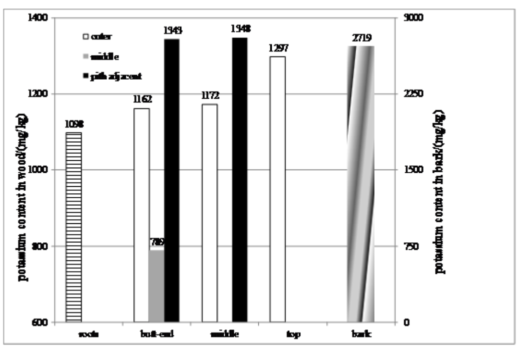

Fig. 2: Potassium content in analyzed wood and bark.

Also in the middle section of the trunk pith adjacent wood contains cca. 13% more potassium than outer wood. Those data are consistent with Krutul and Makowski (2005) who denoted that potassium content in pith adjacent wood from the trunk of Norway maple (*Acer platanoides* L.) gained from the area of Warsaw agglomeration is twice higher in comparison to outer wood.

Sapwood from oak trunks both from polluted and unpolluted environment contains more potassium than sapwood adjacent heartwood, heartwood and pith adjacent heartwood (Krutul and Sacharczuk 1997, Krutul et al. 2014).

In the top part of the trunk, pith adjacent wood, potassium content is cca. 10% higher in relation to outer wood, but cca. 4% lower in comparison to pith adjacent wood from both butt-end and middle trunk sections (Fig. 2).

Wood of the main roots contains similar potassium amount in relation to outer wood but cca. 20% lower than pith adjacent wood. Obtained values are consistent to the data of Krutul and Makowski (2005), who stated that potassium content in the main roots of Norway maple equals 0.1%.

The bark from butt-end section contains twice higher amount of potassium than analyzed wood sections and main roots.

Obtained results of potassium content in the trunk butt-end section are similar to data obtained by Krutul and Makowski (2005) for Norway maple which was also grown in the area of Warsaw agglomeration. These results show that pith adjacent wood contains threefold higher amount of potassium in relation to outer wood and twice higher in comparison to middle wood. Potassium content in bark from butt-end trunk section is twice lower in relation to pith adjacent wood and its content in bark is the highest in relation to analyzed wood zones in trunk as well as in the main roots.

Potassium content in bark from oak stems collected in polluted environment is 15% higher in butt-end section, 7% higher in the middle section of the stem and cca. 40% higher in the top part in relation to the bark from oaks grown in unpolluted environment (Krutul et al. 2014).

Summarizing it may be stated that urban environmental pollution influences the distribution of potassium on the cross- and longitudinal section, as well as its content in the main roots.

Magnesium is the other element which is necessary for correct plants development. In cell walls it is located together with pectins and it much amount of this element is in chlorophyll. Depending on the light exposure its content varies from several to dozens of percent in relation to total content in the leave.

Fig. 3 presents data containing magnesium content in the analyzed material. In butt-end section and in the middle section it is higher in pith adjacent wood in relation to outer wood.

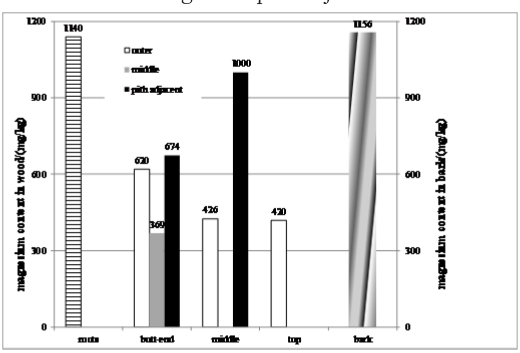

Fig. 3: Magnesium content in analyzed wood and bark.

In the top section of the stem magnesium content is cca. 30% lower in comparison to pith adjacent- and outer wood from butt-end section, two and a half times lower in relation to the content in pith adjacent zone from the middle section.

Changes of magnesium distribution on the trunk cross-section correspond to the data denoted by Krutul and Makowski (2005) regarding butt-end section of Norway maple gained from Warsaw city center.

According to the data of Krutul et al. (2014), magnesium content in oak trunks regardless the environment is higher in sapwood in relation to heartwood adjacent sapwood, heartwood and pith adjacent heartwood. In sapwood zone from trunks grown in the polluted environment magnesium content is higher in relation to unpolluted wood, regardless the cross-section location in the trunk.

Magnesium content in the main roots is two, two and a half times higher in relation to wood, both outer- and pith adjacent- in butt-end section, and only 13% higher in comparison to pith adjacent wood in the middle trunk section.

Krutul and Makowski (2005) stated that the main roots of Norway maple containthree times lower magnesium in relation to roots analyzed in current paper (Fig. 3).

Bark contains 13% to twice higher amount of magnesium in comparison to trunk wood and similar amount like in roots.

According to Krutul and Makowski (2005) it may be stated that bark from Norway maple contains cca. twice lower amount of magnesium in relation to pith adjacent wood.

Obtained results are consistent with the data of Krutul et al. (2014), who stated that magnesium content in oak bark (*Quercus robur* L.) gained from polluted environment is higher in relation to trunk wood, regardless the cross-section location on the trunk. On the other hand, bark from oak grown in unpolluted area contains lower amount of this element in comparison to sapwoodalso regardless the trunk height (Krutul et al. 2014).

Generally, it may be stated that the environmental pollution influences the distribution and content of magnesium in wood on the cross- and longitudinal section, as well as it impacts on this element content in bark.

Elements such as iron (Fe), sodium (Na), aluminum (Al), manganese (Mn), zinc (Zn), strontium (Sr) are classified as heavy metals and microelements in wood chemistry.

Sodium belongs to the elements which are not necessary for correct plants development. However, its presence may favorably influence the plant life processes. In most of the plants this element could be used instead of potassium in its functions (Kopcewicz et al. 1998).

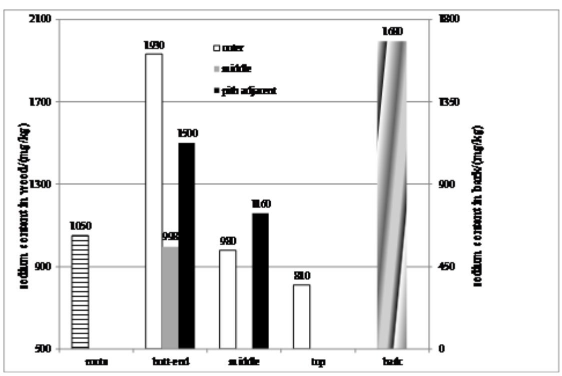

Fig. 4: Sodium content in analyzed wood and bark.

On the basis of the data presented in the Fig. 4 it was denoted that, as the result of salinity, both trunk wood and roots, as well as bark contain high amount of sodium, comparable to potassium content (Fig. 2).

The highest sodium content is stated for wood from butt-end section and equals 998 mg/kg in the middle zone of cross-section, 1930 mg·kg^{-1} in outer wood and 1490 mg·kg^{-1} in pith adjacent wood. Sodium content decreases together with the trunk height and equals 810 mg·kg^{-1} in the top part of the trunk.

Krutul (1996) stated that oak wood (45-, 100- and 120-year old) contains from fifty to hundred times lower amount of sodium in relation to analyzed wood of Norway maple. Sodium content is higher in sapwood than in heartwood.

Sodium content in pine wood equals 15 mg·kg^{-1} to 100 mg·kg^{-1}. Heartwood contains higher amount of this element than sapwood. Both oak and pine wood contains higher amount of sodium in the top part in relation to the middle part and butt-end section (Krutul 1996). Sodium content in the main roots equals 1045 mg·kg^{-1} and is cca. 45% lower in relation to outer wood in butt-end trunk section and cca. 10% lower in comparison to heartwood from the middle part of the trunk.

Krutul and Makowski (2005) denoted that the main roots of Norway maple contain 1270 to 1420 mg·kg^{-1} of sodium.

Sodium content in bark equals 1680 mg·kg^{-1} and is only 15% lower in relation to its content in outer wood from butt-end section of the trunk. Bark from oak (*Quercus petraea* Liebl.) collected from the trunk height 1.8 and 5 m, contain respectively 30 and 37 mg·kg^{-1} of sodium and is twice to sevenfold higher in comparison to trunk wood (Krutul and Makowski 2004).

Summarizing, salinity causes the increase of sodium content in trunk wood, main roots and bark.

Iron (Fe) is the element necessary for proper plants growth. It is collected by plants when pH of soil is low, and if the ground contains high amount of calcium, then iron transforms to the unavailable form (Kopcewicz et al. 1998).

According to the data presented in the Fig. 5, iron content in the outer wood from butt-end section is cca. 25% higher in relation to pith adjacent wood and cca. 30% higher in relation to middle wood.

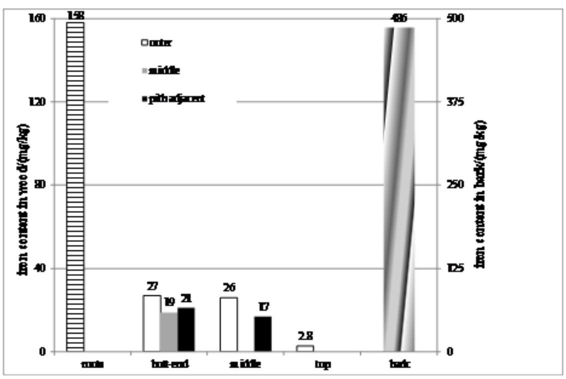

Fig. 5: Iron content in analyzed wood and bark.

Also in the middle section of the trunk iron content in outer wood is cca. 35% higher in comparison to pith adjacent wood. In the trunk top section iron content is similar to the outer wood from butt-end section and middle section.

The main roots contain from six to ten times higher amount of iron than trunk wood. Bark from the butt-end section contains even 486 mg·kg^{-1} (Fig. 5).

On the basis of data denoted by Krutul and Makowski (2005) it may be stated that bark from butt-end trunk section contain cca. thirteen times higher amount of iron in relation to pith adjacent wood and cca. fifteen times higher in relation to outer wood. Also the main roots contain eleven times higher amount of iron in comparison to pith adjacent wood. In butt-end section content of iron is higher in pith adjacent wood in relation to outer wood, what is consistent with data obtained in current paper (Fig. 5).

According to Krutul et al. (2014), oak wood in trunks gained from polluted environment contains cca. twice higher amount of iron in relation to wood from unpolluted environment. Also in bark from polluted environment iron content is from two to three times higher in comparison to bark from unpolluted environment (Krutul and Sacharczuk 1997).

Summarizing, urban environmental pollution causes the increase of iron content in bark and main roots.

Aluminum (in the form of Al^{3+}) in the unfavorable element for most of plants. However if there is high content of copper and manganese in soil, aluminum decreases collection of these elements and partially protects plants against their toxic action.

Fig. 6 presents aluminum content in particular tree parts. It is twice lower in outer wood in relation to pith adjacent wood in butt-end section and cca. 30% higher for the middle trunk part. In the top part of the trunk aluminum content in wood equals 4 $mg \cdot kg^{-1}$ and is several times lower in comparison to wood from butt-end and middle sections.

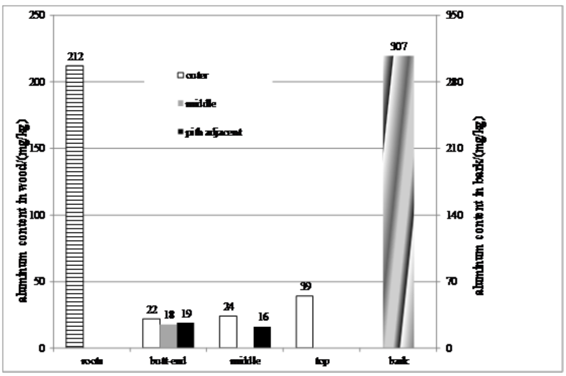

Fig. 6: Aluminum content in analyzed wood and bark.

Aluminum content in the main roots and bark is more than a dozen times higher than in wood in butt-end and middle sections and dozens times higher in relation to the top part of the trunk (Fig. 6). This content in wood, bark and main roots is similar to iron content and higher than manganese and zinc content.

Krutul and Makowski (2005) stated that wood from outer zone of Norway maple gained from urban environment contains 30% lower amount of aluminum than pith adjacent wood. Its content in bark and main roots is from over a dozen to dozens times higher in comparison to trunk wood. These results are consistent with those obtained in current studies.

According to data of Meisch et al. (1986), aluminum content in wood of Fagus sylvatica is higher in outer zone than in middle zone and equals correspondingly 5 and 50 $mg \cdot kg^{-1}$. Also in analyzed in current paper trunk wood from butt-end and middle section outer wood contains more aluminum (24 to 29 $mg \cdot kg^{-1}$) than pith adjacent wood (16.2 to 19.3 $mg \cdot kg^{-1}$).

Krutul et al. (1999) denoted that aluminum content in sapwood of *Pinus sylvestris* L. is lower in relation to heartwood (5 and 10 $mg \cdot kg^{-1}$ respectively) and in bark it is over a dozen times higher (142 $mg \cdot kg^{-1}$).

Summarizing, the environmental pollution increased aluminum content in bark and main roots.

Manganese (Mn) belongs to elements necessary for proper plants development. It forms unstable complexes with some enzymes, being the ion bridge between substrate and enzyme. It takes a part in reactions of water decomposition and oxygen release during photosynthesis, as well as activate many enzymes participating in metabolism of proteins, sugarcanes and lipids. Manganese deficiency causes longitudinal growth braking as well as side roots creation. It also decreases the resistance for low temperatures.

Manganese occur in plants on different oxidation state and it is collected from soil with the second and third oxidation state (Kopcewicz et al. 1998).

According to data presented in the Fig. 7, manganese content in trunk wood and in the main roots is low and equals from 2 to 13 mg·kg^{-1}. Pith adjacent wood contains twice higher amount of manganese in relation to outer wood.

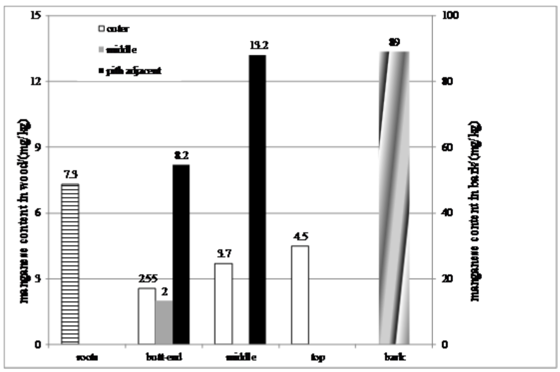

Fig. 7: Manganese content in analyzed wood and bark.

Obtained results are consistent with the data of Krutul and Makowski (2005), who stated that outer wood of Norway maple gained from urban environment contains lower amount of manganese than pith adjacent wood.

Krutul and Makowski (2004) denoted that trunk wood from oak (*Quercus petraea* Liebl.) height of 1.8 and 5 m contains correspondingly 50.3 and 47.0 mg·kg^{-1} (sapwood), 10.3, 9.7 mg·kg^{-1} (heartwood).

According to Watmough et al. (1998), manganese content in sugar maple (*Accer saccharum* Marsh.) regardless the habitat varies from 4.5 to 10.0 mg·kg^{-1}.

Krutul (1996) stated that manganese content in 45-, 100- and 120-year old oak woodis lower in sapwood (21.5 to 62.2 mg mg·kg^{-1}). 80-, 90- and 160-year old Scots pine wood (*Pinus sylvestris* L.) contains 20 to 99 mg·kg^{-1} manganese (heartwood) and 13.5 to 60.0 mg·kg^{-1} (sapwood).

Manganese content in the main roots of Norway maple (*Acer platanoides* L.) gained from unpolluted environment equals 7.3 mg·kg^{-1} and is cca. five fold lower in relation to the same material collected in urban area (Krutul and Makowski 2005).

Bark contains seven- to forty five times higher amount of manganese in comparison to trunk wood and thirteen times higher in relation to the main roots.

Obtained results are consistent with the data of Krutul and Makowski (2005), where bark from butt-end section of Norway maple contains similar amount of analyzed element (92.2 to 104.0 mg·kg^{-1}).

Summarizing, environmental pollution causes the decrease of manganese content in trunk and roots.

Zinc is the element necessary for proper plants development and it is the component or influences the activity of many enzymes, like carbonic anhydrases, carboxypeptidase, alcoholic dehydrogenase and superoxide dismutase with copper. It takes a part with sugarcanes metabolism regulations and proteins synthesis. It is also an integral part of cell walls and structural component of ribosomes. Zinc and phosphorus are antagonistic elements and their incorrect ration causes the decrease of zinc collection by plants and braking of transport from roots to trunk (Kopcewicz et al. 1998).

As it arises from the data presented in the Fig. 8, zinc content in trunk heartwood from analyzed Norway maple is cca. 20% higher in butt-end section to even 65% higher in the middle part of the trunk in comparison to the outer wood. Obtained results are consistent with data denoted by Krutul and Makowski (2005), where zinc content in butt-end section of Norway maple trunk is twice higher in heartwood than in outer wood.

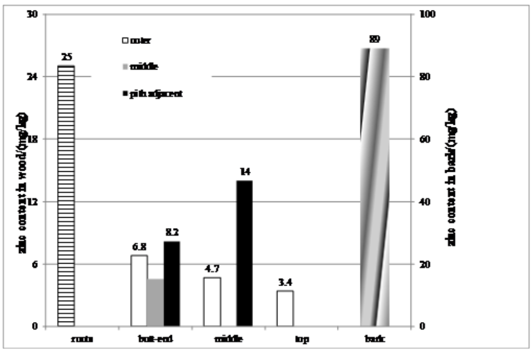

Fig. 8: Zinc content in analyzed wood and bark.

Krutul et al. (1999) stated that zinc content in Scots pine wood (*Pinus sylvestris* L.) is similar on the whole cross-section and equals cca. 10 mg·kg^{-1}. On the other hand on the cross-section of oak wood (*Quercus petraea* Liebl.) zinc content is twice higher in sapwood in relation to heartwood (Krutul and Makowski 2004). Top part of analyzed Norway maple trunk contains two to four times lower amount of zinc than pith adjacent wood in other trunk sections and cca. 30% lower in relation to outer wood.

According to Watmough et al. (1998), sugar maple (*Acer saccharum*) collected from four habitats in Canada situated along an urban-rural gradient extending north-eastwards from Toronto in southern Ontario contains 2.0 to 5.8 mg·kg^{-1} of Zinc in 1918 and 2 to 7 m mg·kg^{-1} in 1993.

Zinc content in the main roots is twice to sevenfold higher in comparison to trunk wood. It is consistent to results obtained by Krutul and Makowski (2005) where the main roots of Norway maple contain twice to four times higher amount of zinc in relation to trunk wood. Also bark contains two and a half times higher amount of zinc in comparison to trunk wood and threefold higher than the main roots. Krutul and Makowski (2004) denoted that zinc content in bark from oak trunk (*Quercus petraea* Liebl.) is higher in relation to both sapwood and heartwood. This content is cca. fourteen times lower in trunk wood.

The environmental pollution causes the decrease of zinc content in trunk wood and the increase or this content in bark.

Strontium (Sr^{2+}) belongs to elements which are antagonistic to calcium (Ca^{2+}). There are many papers concerning absorption and translocation of strontium by plants and roles of root and shoot tissues in transport and accumulation (Kozhevnikova et al. 2006, 2009, Seregin and Kozhevnikova 2007, Moyen and Robin 2010, Isermann after Skoryna 1981, Capo et al. 1998). On the other hand, there is a lack of studies about the content of this element in particular parts of the tree.

On the basis of the data presented in the Fig. 9 it may be stated that strontium content is similar to the content of other elements necessary for correct trees development, like manganese (Fig. 7) and zinc (Fig. 8).

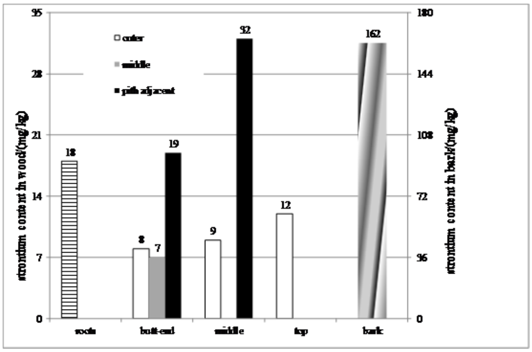

Fig. 9: Strontium content in analyzed wood and bark.

Strontium content in the butt-end and middle sections of the trunk is cca. twice higher in pith adjacent wood in relation to outer wood. It the trunk top part strontium content is 40% higher in comparison to its content in outer wood from butt-end section and 25% higher in relation to outer wood from the middle part.

Obtained data are consistent with those denoted by Krutul and Makowski (2005). Strontium content in pith adjacent wood of Norway maple from butt-end section is cca. 40% higher in relation to outer wood and cca. 30% higher than in heartwood adjacent sapwood.

Strontium content in the main roots equals 18 $mg \cdot kg^{-1}$ and is twice higher in relation to outer wood from both butt-end and middle sections (Fig. 9). It is compatible to the results of Krutul and Makowski (2005), where the main roots strontium content varies from 17.0 to 20.2 $mg \cdot kg^{-1}$.

Bark contains 162 $mg \cdot kg^{-1}$ of strontium, what is over a dozen to dozens of times higher in relation to trunk wood and the main roots. These results are also consistent with Krutul and Makowski (2005), where bark from Norway maple trunk gained from urban environment contains 157 to 159 m $mg \cdot kg^{-1}$ of strontium.

Summarizing it may be stated that strontium content in butt-end and middle sections decreases in the direction from pith to perimeter and in bark its content is cca. twice higher than manganese and zinc content.

CONCLUSIONS

As the result of the urban environmental pollution following changes in Norway maple (*Acer platanoides* L.) take place:

Influence on distribution and content of calcium (Ca^{2+}), potassium (K^+) and magnesium

(Mg^{2+}) on the cross- and longitudinal section, as well as content in bark.

Salinity of the environment causes the increase of sodium content, similar to potassium content, in trunk, roots and bark.

The increase of the iron and aluminum content in the main roots and bark. The decrease of manganese in trunk and the main roots. The decrease of zinc content in trunk wood and the increase of this content in bark. Increased strontium content in relation to manganese and zinc.

REFERENCES

1. Capo, R. C., Stewart, B. W., Chadwick, O. A., 1998: Strontium isotopes as tracers of ecosystem processes: theory and methods, Geoderma 82: 197-225.
2. Kopcewicz, J., Lewak, S. (ed.), 1998: Plants physiology basics (in Polish). W.N. PWN Warszawa 774 pp.
3. Krutul, D., 1996: Distribution of mineral substances along and cross trunk in pine wood (*Pinus sylvestris* L.) and oak wood (*Quercus petraea* Liebl.), 10th Scientific Conference: Wood –engineering material. Faculty of Wood Technology, Warsaw University of Life Sciences. Warsaw 16 (02): 177-188.
4. Krutul, D., Sacharczuk, A., 1997: Content of extractive and mineral substances in the bark and oak wood (*Quercus robur* L.), 11th Scientific Conference: Wood – ecological material. Faculty of Wood Technology, Warsaw University of Life Sciences. Warsaw 18 (11): 227-234.
5. Krutul, D., Kazem-Bek, D., Sacharczuk, A., 1999: Content of some elements in the bark and wood of Scots pine (*Pinus sylvestris* L.), 13th Scientific Conference: Wood – material of comprehensive destination and usage. Faculty of Wood Technology, Warsaw University of Life Sciences. Warsaw 16 (11): 73-81.
6. Krutul, D., Makowski, T., 2004: Content of the mineral substances in the oak wood (*Quercus petraea* Liebl.), Annals of Warsaw Agricultural University SGGW. Forestry and Wood Technol. 55: 315-320.
7. Krutul, D., Makowski, T., 2005: Influence of agglomeration on content of Norway maple (*Acer platanoides* L.) Annals of Warsaw Agricultural University SGGW. Forestry and Wood Technol. 56: 369-376.
8. Krutul, D., Zielenkiewicz, T., Zawadzki, J., Radomski, A., Antczak, A., Drożdżek, M., 2014:Influence of urban environment originated heavy metal pollution on the extractives and mineral substances content in bark and wood of oak (*Quercus robur* L.), Wood Research 59 (1): 177-190.
9. Kozhevnikova, A. D., Seregin, J. V., Bystrova, E. J., Ivanov, V. B., 2006: Effects of heavy metals and strontium on division of root cap cells and meristem structural organization, Russian Journal of Plant Physiology 54 (2): 257-266.
10. Kozhevnikova, A. D., Seregin, J. V., Bystrova, E. J., Belyaeva, A. J., Kataeva, M. N., Ivanov, V. B., 2009: The effects of lead, nickel and strontium nitrates on cell division and elongation in maize roots, Russian Journal of Plant Physiology 56 (2): 242-250.
11. Moyen, C., Roblin, G., 2010: Uptake and translocation of strontium in hydroponically grown maize plants, and subsequent effects on tissue ion content, growth and chlorophyll a/b ratio: comparison with Ca effects, Environmental and Experimental Botany 68: 247-257.

12. Rademacher, P., Bauch, J., Puls, J., 1986: Biological and chemical investigations of the wood from pollution – affected spruce (*Picea abies* L. Karst.), Holzforschung 40 (6): 331-338.
13. Skoryna, S. C., 1981: Handbook of stable strontium. New York, Pp 65-86.
14. Watmough, S. A., 1997: An evaluation of the use of dendrochemical analyses in environmental monitoring, Environmental Review 5: 181-201.
15. Watmough, S. A., Hutchinson, T. C., Sager, E. P. S., 1998: Changes in tree ring chemistry in sugar maple (*Acer saccharum* Marsh.) along an urban – rural gradient in southern Ontario, Environmental Pollution 101 (3): 381-390.

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