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CHANGES IN HEALTH STATUS AND CHEMICAL COMPOSITION OF TREE LEAVES OF THE CRIMEAN LINDEN IN THE YEARS 2000 AND 2009

ZMIANY STANU ZDROWOTNEGO I SKŁADU CHEMICZNEGO LIŚCI DRZEW LIP KRYMSKICH W LATACH 2000 I 2009

Słowa kluczowe: środowisko miejskie, zasolenie, ubytek drzew, równowaga jonowa, stres solny, lipa.
Key words: city environment, deicing, tree decline, ionic balance, salt stress, linden.

Przedmiotem badań były drzewa lipy krymskiej (Tilia 'Euchlora'), rosnące w pasie międzyjezdniowym al. Żwirki i Wigury w Warszawie. Próbki liści do oznaczeń chemicznych pobierano z każdego drzewa oddzielnie w ostatnim tygodniu lipca w latach 2000 i 2009. W liściach oznaczono mikro- i makroelementy oraz typowe zanieczyszczenia środowiska miejskiego: N, P, K, Mg, Ca, Cl, Na, Cu, Zn, Fe, Mn, Pb i Cd. Stan zdrowotny liści lip krymskich w 2009 r. był lepszy niż w 2000 r., ale u większości badanych drzew poziom uszkodzeń musiał niekorzystnie wpływać na ich wzrost i rozwój. Zawartość chloru i sodu bardzo silnie wpływała na pogorszenie stanu zdrowotnego liści. Wraz ze wzrostem zawartości tych pierwiastków statystycznie istotnie malała zawartość N i S (podstawowych składników aminokwasów białkowych). Ujemna wysoka wartość współczynnika korelacji wskazuje, że zwiększenie zawartości podstawowych makroelementów (N, P, K i S) powoduje poprawę

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stanu zdrowotnego badanych drzew. Na podstawie analizy korelacji najsilniejsze zależności stwierdzono między zawartością w liściach Ca i Mg oraz N i S. Nie stwierdzono wpływu zawartości makroelementów (Ca i Mg) i mikroelementów (Fe, Mn i Zn) oraz metali ciężkich (Cd i Pb) na stan zdrowotny drzew. Zależności te były dodatnie, co oznacza że wraz ze wzrostem zawartości jednego pierwiastka obserwowano zwiększenie zawartości drugiego pierwiastka. Porównując opracowane statystycznie wyniki wpływu zawartości pierwiastków na stan zdrowotny liści w 2000 i 2009 r. nie stwierdzono istotnych różnic.

1. INTRODUCTION

In cities we notice the dying out of the trees, caused a gradual weakening of their vitality. This process mainly afflicts street side trees . In Europe more than 700 000 trees die out every year [Flückiger and Braun, 1981]. In Liverpool, out of the city trees that were planted in the recent years, 39 % had died out within five years [Pauleit et al, 2002]. In Warsaw in the years 1973–2010 more than 70 % of the trees growing along four main arteries in the city center had to be removed [Dmuchowski and Badurek 2004; Dmuchowski et al. 2011].

He reports as the main cause of the worsening condition of the trees in cities the application of NaCl in de-icing of streets in winter. The accumulation of NaCl occurs mainly within 10 m from the road [Astebol et al. 1996], however an elevated concentration of NaCl in the soil was also observed in distances from the road as high as tens up to a few hundred meters.

Sodium chloride causes perturbations in the flow of physiological processes, including photosynthesis and breathing [Marschner 1995, Larcher 1995] and necrosis on the leaf blade surface, as well as wrinkling, curling, dying away and premature falling off of leaves, in consequence the tree dies [Dmuchowski et al. 2007, Munns and Tester 2008].

The purpose of the study was to determine the changes in the influence of soil pollution with sodium chloride on the health status of the Crimean Linden, and the chemical composition of their leaves in the year 2009 compare to the year 2000.

2. MATERIALS AND METHODS

The subjects of research were 136 trees of the Crimean Linden (*Tilia* 'Euchlora') growing in the median strip along Żwirki and Wigury Avenue. This is one of the main arteries of Warsaw, and is characterized by a high intensity of traffic. The control area was a park next to the Soviet Soldiers Cemetery, distanced about a 100 m away, but separated from the road by dense hedges of trees and bushes.

The evaluation of the leaf health status was conducted using a classification consisting of six health categories (leaf damage index), where "0" meant a "healthy" tree, and "5" a seriously damaged one (damage of up to 50 % of the leaf surface area). The observations of the health status were conducted in the middle of September. The leaf samples

used for chemical determination were collected separately from each tree during the last week of July in the years 2000 and 2009. The leaves were collected from the outer belt of the tree crown – along its complete perimeter at the height of approximately 4 m. Phosphorus as well as the metals: magnesium, calcium, potassium, sodium, zinc, copper, iron, molybdenum, cadmium and lead after a dry mineralization in a muffle furnace [Allen et al 1974] were determined by the atomic absorption spectrophotometry method using the Perkin Elmer 1100B apparatus [Perkin Elmer 1990]. Chlorine was determined by the titrimetric method using an ion-selective electrode and the ionmeter Orion type 701a [LaCroix et al. 1970], sulphur was determined using the LECO 132 apparatus [LECO corporation 1987], and the overall nitrogen – using the Kleidahl's method with the Foss Tecator 1035 analyzer. The leaves were not washed before the analysis.

To compare the mean values of the elements present in the leaves of a various health status, the one-way analysis of variance was conducted (the factor was the level of leaf damage). Multiple comparisons of the means were performed using Tukey's method. On the basis of these analyses homogenous groups of the means were distinguished. Relationships between the contents of the elements and the leaf health status were evaluated using Pearson's correlation coefficient and a simple linear regression [Sokal and Rohlf 1995]. For all analyses the significance level was set at 0.05. The statistical analyses were performed in Statistica 8.0 (StatSoft) software and the figures were prepared using MS Excel.

3. RESULTS AND DISCUSSION

The deciding factor in the correct growth and development of the trees is the health status of their leaves. In the first July term of observations the leaf health status of the Crimean Linden studied was relatively good in both years of the study (tab. 1.). In the year 2000 64 %, and in the year 2009 67 % of the trees had leaves with relatively little damage (the damage index 0-1). In the same term only 2 % in 2000, and in 2009 5 % of the trees had significant damage to the leaves (the damage index 4–5). During the vegetation season the leaf health status was getting progressively worse. By September 2009 slightly damaged were only 41% of the trees (the damage index 0–1), and 14 % were characterized by a significant damage of the leaf blade (the damage index 4–5). In 2000 by September no tree could be classified as "healthy" (leaf damage index 0–1), and the number of highly damaged was all the way up to 43 %. The trees in 2009 were characterized by a better leaf health status than in the year 2000, but for the majority of the trees studied the level of damage must have had a negative influence on their growth and development.

The health status of the Crimean Linden from Żwirki and Wigury Avenue was relatively better than that of the same species of trees from other streets in the center of Warsaw [Badurek et al. 2001, Dmuchowski et. al. 2001]. This result could be explained by relatively better conditions for tree growth at Żwirki and Wigury Avenue – a wide lawn area, rath-

er than the concrete covered areas with narrow lawns, as typical places where street side trees grow in Warsaw in Warsaw.

The soil pollution with NaCl, resulting from winter de-icing of streets, is considered one of the main causes of the poor health status of the city trees [Brogowski et al. 1977, Alaoui-Sosse et al. 1998, Brogowski et al. 2000, Dmuchowski and Badurek 2004, Dmuchowski et al. 2007, Oleksyn et al. 2007, Cekstere et al. 2008, Lundmark and Jansson 2008, Polanco et al. 2008, Munck et al. 2009, Hanslin 2011].

The average content of chlorine in the leaves of the Crimean Linden in 2009 increased with the worsening off of the leaf health status and fluctuated depending on the degree of their damage from 0.98 (the damage index 0) to 1.88 % (the damage index 5) (Tabl. 2, Fig. 1). The leaves of the control trees contained 0.32 % of chlorine. The leaves of all the Linden street trees studied contained more chlorine than the toxicity level quoted in literature at 0.6 % [Shortle and Rich 1970; Czerwiński 1978; Pracz 1978; Chmielewski et al.1985; Pauleit 1988].

Table 1. Percentage shares of particular tree health categories of the Crimean Linden as a function of the leaf damage index

Tabela. 1. Procentowy udział poszczególnych kategorii zdrowotnych drzew lipy krymskiej wg indeksu uszkodzenia liści

Index leaf damage	Percentage shares			
	2000		2009	
	July	September	July	September
0	14	0	38	11
1	50	0	29	30
2	26	8	16	20
3	9	49	11	25
4	1	38	4	9
5	1	5	1	5

Table. 2. Comparison of the average content of chlorine (%) and sodium (mg/kg) in the leaves of different health status

Tabela. 2. Porównanie średniej zawartości chloru (%) i sodu (mg/kg) w liściach o różnym stanie zdrowotnym

Index leaf damage	Cl, %		Na, mg/kg	
0	0.98	b	192.7	a
1	1.18	b	199.7	a
2	1.46	c	230.3	a
3	1.59	cd	601.6	a
4	1.77	cd	1470.6	b
5	1.88	d	3291.2	c
Control	0.35	a	86.4	a

Note: Different letters show statistically significant differences.

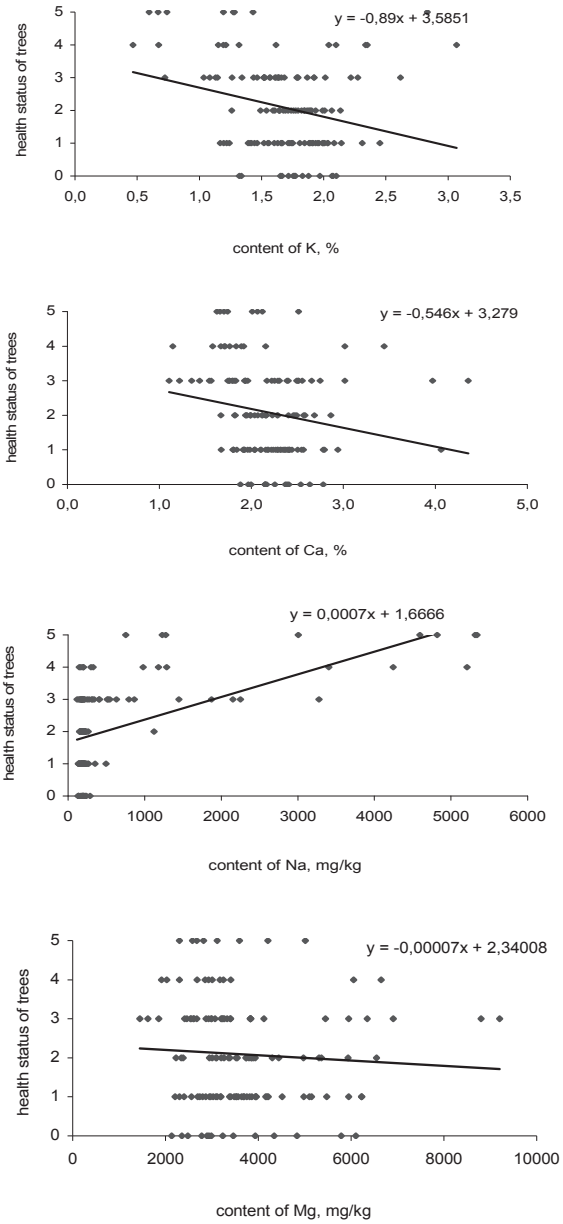

Fig. 1A. Comparison of the average content of chlorine and sodium in the leaves of the Crimean Linden growing in the median strip of Żwirki i Wigury Avenue

Rys. 1A. Zależność między średnią zawartością poszczególnych pierwiastków w liściach a stanem zdrowotnym lip krymskich rosnących w pasie międzyjezdniowym al. Żwirki i Wigury w 2009 r.

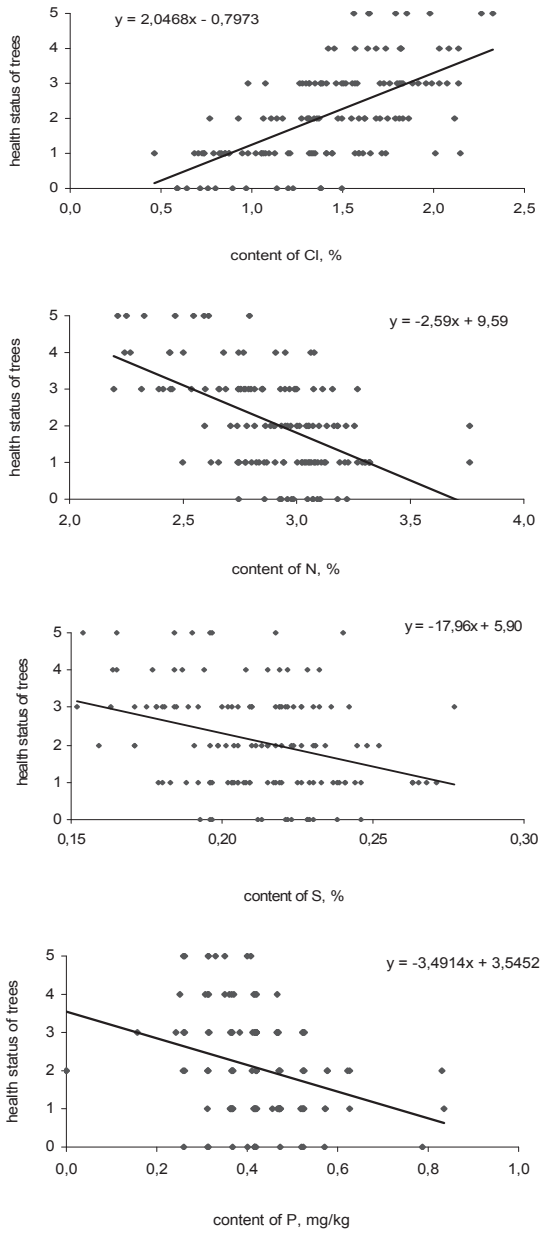

Fig. 1B. Comparison of the average content of chlorine and sodium in the leaves of the Crimean Linden growing in the median strip of Żwirki i Wigury Avenue

Rys. 1B. Zależność między średnią zawartością poszczególnych pierwiastków w liściach a stanem zdrowotnym lip krymskich rosnących w pasie międzyjezdniowym al. Żwirki i Wigury w 2009 r.

The differences in the content of sodium in the leaves as a function of their health status were much greater than in the case of chlorine (Table. 2, Fig. 1). Leaves with no damage (the damage index – 0) contained on the average 193 mg/kg of sodium, and those highly damaged (the damage index 4 and 5) respectively 3291 mg/kg. The leaves of the control trees contained on the average 86 mg/kg of sodium. The interpretation of results of the contents of sodium in the leaves of trees is made difficult because there is no information in the literature about the limit levels of toxicity. Sodium is characterized by high lability in soils as well as in plants, and its excess results primarily in a disturbance of the ionic balance, and not in a simple toxic action [Alaoui et al. 1998].

Table 3 presents the statistical analysis (correlation coefficient) of the relationship between the value of the leaf damage index, and their content of the micro- and macroelements as well as typical pollutants of the city environment. The purpose of this experiment was a comparison of the influence of the environmental pollution on the health status of trees in the year 2000, and after nine years (2009).

Table. 3. Dependency (correlation coefficient) between the value of leaf damage index, and the content of selected elements in the leaves of the Crimean Linden

Tabela 3. Zależność (współczynnik korelacji) między wartością indeksu uszkodzenia liści, a zawartością wybranych pierwiastków w liściach lip krymskich

Element	Damage leaf index, years	
	2000	2009
Cl	**+ 0.55**	**+ 0.62**
N	**- 0.30**	**- 0.54**
P	**- 0.29**	**- 0.30**
S	**- 0.20**	**- 0.34**
Ca	- 0.15	- 0.19
Mg	- 0.18	- 0.07
K	**- 0.21**	**- 0.26**
Na	**+ 0.43**	**+ 0.57**
Fe	- 0.05	- 0.06
Zn	- 0.10	- 0.12
Mn	+ 0.05	- 0.01
Cu	- 0.19	**- 0.38**
Pb	+ 0.04	+ 0.10
Cd	+ 0.02	+ 0.18

Note: The values indicating occurrence of statistically significant correlations at level of $P<0.05$ were differentiated in bold font.

The results clearly indicate unfavorable influence of chlorine and sodium content in leaves on their health status in both years of the survey. The proof of this is a high positive value of the correlation coefficient. The higher the levels of content of these elements the worse the leaf health status. On the basis of regression equations we can state that an

increase of chlorine content by 1 % causes an increase of leaf health status by 2 degrees (units). In case of sodium the increase of content by 1000 mg/kg causes the increase in health status by 0.7 degree (unit). Chlorine had a stronger unfavorable effect on the health status than sodium because the values of the correlation coefficient were respectively equal 0.55 and 0.62 for Cl in 2000 and 2009 while for Na they were 0.43 and 0.57, respectively. The correlations were stronger in 2009 than in 2000.

Statistical analyses did not prove any significant effect of the metal contents on their health status. Values of correlation coefficients were less than the critical value 0.20 for almost all microelements and heavy metals. The only exception was the content of copper, which was negatively correlated with the leaf health status in 2009.

Contents of elements important for basic physiological functions in plants i.e. nitrogen, phosphorus, potassium and sulphur were negatively correlated with the health status in both years. The higher the content of these elements the better the leaf health status. All these correlations were significant and the strongest one was observed for nitrogen. On the basis of regression equations (Fig. 2) we can state that an increase of nitrogen content by 1 % causes a decrease of the leaf health status by 2.6 degree. In case of potassium an increase by 1% of the content caused a decrease in health status by 0.9 degree for K and an increase by 0.1 % caused a decrease in health status by 1.8 and 1.35 degree respectively for sulphur and phosphorus.

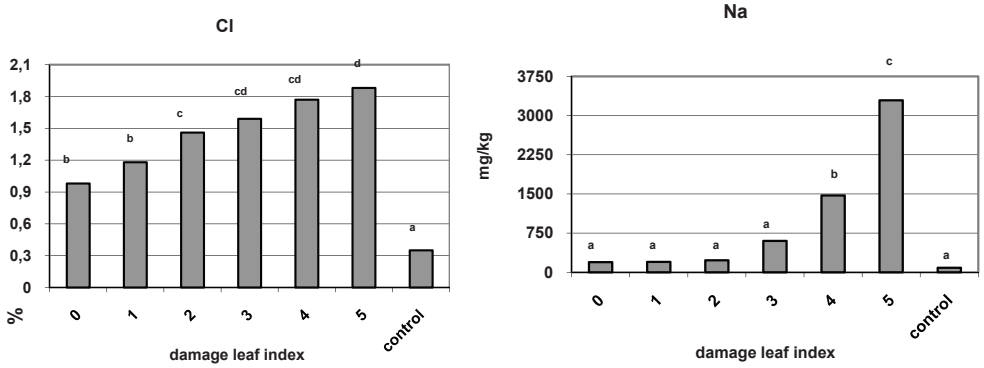

Fig. 2. Dependency between the average content of specific elements in the leaves and the health status of the Crimean Linden in the year 2009; different letters show statistically significant differences

Fig. 2. Porównanie średniej zawartości chloru i sodu w liściach lip krymskich rosnących w pasie międzyjezdniowym Żwirki i Wigury w 2009 r.; różne litery oznaczają statystycznie istotne różnice

Values of correlation coefficients between the leaf health status and the contents of magnesium and calcium did not prove any significant relationships.

Similar results were obtained in both years (2000 and 2009) of the study. The levels of correlations were similar.

Correlations between the contents of elements important for basic physiological functions and the contents of elements responsible for soil contamination (Cl and Na) are presented in Table 4. On the basis of the correlation analysis some very strong relationships were detected between the contents of calcium and magnesium as well as between those of nitrogen and sulphur. The correlations were positive; it means that an increase of one element causes an increase of the other element.

Table 4. Correlation coefficients for the contents of specific elements in the leaves in the year 2009

Tabela 4. Współczynniki korelacji między zawartością poszczególnych pierwiastków w liściach w roku 2009

Element	K	Mg	Ca	Na	Cl	N	P
Mg	0.10						
Ca	**0.36**	**0.64**					
Na	**-0.29**	0.03	-0.05				
Cl	0.05	**0.25**	0.06	**0.29**			
N	**0.38**	0.07	**0.24**	**-0.40**	**-0.24**		
P	**0.29**	0.08	0.13	**-0.27**	-0.06	**0.47**	
S	**0.18**	0.03	0.07	**-0.18**	**-0.21**	**0.58**	**0.32**

Note: Bold correlation coefficients signify statistically confirmed relevant dependencies at level of $P<0.05$.

In case of the elements very strongly correlated with the health status i.e. sodium and chlorine, significant negative correlations were detected with nitrogen and sulphur i.e. elements important for amino acids. It means that an increase of the content of sodium and chlorine caused a decrease of the content of nitrogen and sulphur. Moreover, negative correlations between the content of sodium with the content of potassium and phosphorus were observed. The content of calcium was very strongly correlated with the content of magnesium and to a lesser degree with potassium.

4. CONCLUSIONS

Crimean Linden in 2009 were characterized by a better leaf health status than in the year 2000, but in the majority of the trees studied the level of damage must have had a negative influence on their growth and development.

The content of chlorine and sodium influenced very strongly the worsening off of the leaf health status, as indicated by a high value of the correlation coefficient.

A high negative value of the correlation coefficient indicates that increasing the content of macroelements: nitrogen, phosphorus, potassium and sulphur in the leaves results in their improved health status.

No influence was found by the presence of macroelements: calcium and magnesium, microelements: iron, manganese and zinc, and heavy metals: lead and cadmium on the health status of the trees.

On the basis of the correlation analysis the strongest relationships were found between the leaf content of calcium and magnesium as well as nitrogen and sulphur. The correlations were positive; it means that a content increase of one element causes an increase in the content of the other element.

As the content of chlorine and sodium increased, there was a statistical decrease in the content of nitrogen and sulphur, basic ingredients of protein aminoacids.

Comparing statistically processed results of the influence of element content on the leaf health status in 2000 and 2009, no significant differences were found. All the dependencies and regularities were present practically at the same levels in both years of research.

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REFERENCES

ALAOUI-SOSSE B., SEHMER L., BARNOLA P., DIEZENGREMEL P. 1998. Effect of NaCl salinity on growth and mineral partitioning in Quercus robur L., arhythmically growing species. Trees 12: 424–430.

ALLEN S. E., GRIMSHAW H. N., PARKINSON J. A., QUARMBY C. 1974. Chemical Analysis of Ecological Materials. Blackwell Scientific Publications, Oxford**.**

ASTEBOL S. O., PEDERSEN P. A., ROHR P .K., FOSTAD O., SOLDAL O. 1996. Effects of De-icing Salts on Soil Water and Vegetation. Norwegian National Road Administration, Report MITRA, 05/96, Oslo: 63.

BADUREK M., DMUCHOWSKI W., SUPŁAT S., WÓDKIEWICZ M. 2001. Stan zdrowotny drzew przyulicznych w centrum Warszawy. W: R. Siwicki (red.) Reakcje biologiczne drzew na zanieczyszczenia przemysłowe. Wyd. Bogucki, Poznań: 373–381.

BROGOWSKI Z., CZARNOWSKA K., CHOJNICKI J., PRACZ J., ZAGÓRSKI Z. 2000. Wpływ stresu solnego na stan chemiczny liści drzew z terenu miasta Łodzi. Roczn. Gleboznawcze 51, 1–2: 17–28.

BROGOWSKI Z., CZERWIŃSKA Z., PRACZ J., 1977. Wpływ soli NaCl na stan równowagi jonowej niektórych drzew parkowych. Roczn. Nauk Roln. 102(2): 51–64.

CEKSTERE G. NIKODEMUS O., OSVALDE A. 2008. Toxic impact of the de-icing material to street greenery in Riga, Latria. Urban Forestry and Urban Greening 7(3): 207–217.

CHMIELEWSKI W. MOLSKI B. SUPŁAT S. 1985. Index of green leaves areas as indicator of functional use of street trees in the city. W: (red.) Creation and Protection of Verdure in the Urbanized landscape. I. Supika. VEDA, Bratislava: 131–137.

CZERWIŃSKI Z., 1970. Wpływ związków chemicznych stosowanych do odśnieżania na roślinność przyuliczną w Warszawie. Ogrodnictwo, 10: 296–300.

DMUCHOWSKI W., BACZEWSKA A. H., GOZDOWSKI D. 2011. Reaction of street trees on the condition in Warsaw. Ecological Questions (in Press)

DMUCHOWSKI W., BADUREK M. 2004. Chloride and sodium in the leaves of urban trees in Warsaw in connection to their health condition. Chemia i Inżynieria Ekologiczna 11,4–5: 297–303.

DMUCHOWSKI W., KURCZYŃSKA E., CHMIELEWSKI W., BADUREK M. 2001. Wzrost i rozwój lipy krymskiej w nasadzeniach przyulicznych. W: R. Siwicki (red.) Reakcje Biologiczne Drzew na Zanieczyszczenia Przemysłowe. Wyd. Bogucki, Poznań: 629–635.

DMUCHOWSKI W., SOŁTYKIEWICZ E., WOŹNIAK J. 2007. The effect of urban environment on the phenological development of *Tilia* 'Euchlora' trees. Monographs of Botanic Garden: 1141–1145.

FLÜCKIGER W., BRAUN S. 1981. Perspectives of reducing the deleterious effect of de-icing salt upon vegetation. Plant Soil 62(3): 527–529.

HANSLIM H.M. 2011. Short-term effects of alternative de-icing chemicals on tree sapling performance. Urban Forestry and Urban Greening 10:53–59.

LACROIX R. L., KEENEY D. R., WALSH L. M. 1970. Potentiometric titration of chloride in plant tissue extracts using the chloride ion electrode. Soil Science And Plant Analysis 1(1): 1–6.

LARCHER W., 1995. Physiological Plant Ecology, fifth ed. Springer-Verlag, Berlin.

LECO CORPORATION 1987. Application Bulletin. St. Joseph, Mi.

LUNDMARK A., JANSSON P. E. 2008. Estimating the Fate of De-icing Salt in a Roadside Environment by Combining Modelling and Field Observations. Water, Air, Soil Pollution 195,1–4: 215–232.

MARCHNER H. 1995. Mineral nutrition of higher plants. Academic Press, London: 889.

MORTON S., ROBERTS D. 1991. ATI unicam, atomic absorption spectrometry – methods manual. Issue 2, Unicam LTD: 398.

MUNCK I. A., NOWAK R. S., CAMILLI K., BENNETT C. 2009. Long-term impacts of de-icing salts on roadside trees in the Lake Tahoe Basin. Phytopathology 99,6: 91.

MUNNS, R., TESTER, M. 2008. Mechanisms of salinity tolerance. Annual Review of Plant Biology 59: 651–681.

OLEKSYN J., KLOEPPEL, B. D., LUKASIEWICZ S., KAROLEWSKI P., REICH P. B. 2007. Ecophysiology of horse-chestnut (*Aesculus hippocastanum* L.) in degraded and restored urban site. Pol. J. Ecol. 55,2: 245–260.

PAULEIT S, JONES N., GARCIA-MARTIN G., GARCIA-VALDECANTOS J.L., RIVIČRE L. M., VIDAL-BEAUDET L., BODSON M., RANDRUP T. B. 2002. Tree establishment practice in cities and towns—results from a European survey. Urban Forestry and Urban Greening 5,3:111–120.

PAULEIT S. 1988. Vitalitätskartierung von Stadtbäume in Mŭnchen. Garten + Landschraft 7: 38–40.

PERKIN ELMER. 1990. Analytical methods for atomic absorption spectrophotometry. Bodenseewerk, Pub. B353: 233.

POLANCO M. C., ZWIĄZEK J. J., VOICU M. C. 2008. Responses of ectomycorrhizal American elm (*Ulmus americana*) seedlings to salinity and soil compaction. Plant Soi. 308,1–2: 189–200.

PRACZ J., 1978. Reakcja drzew i krzewów na zasolenie gleby chlorkiem sodu. Praca doktorska wykonana w Instytucie Gleboznawstwa SGGW-AR w Warszawie. Warszawa, maszynopis: 149 s. + 39 tab.

SHORTLE W. C., RICH A. E. 1970. Relative sodium tolerance of common roadside trees in southeastern New Hampshire. Plant Dis. Rep. 54: 360–362.

SOKAL R. R., ROHLF F. J. 1995. Biometry: the principles and practice of statistics in biological research. W.H. Freeman and company, New York: 887.