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EFFECT OF SALT STRESS CAUSED BY DEICING ON THE CONTENT OF MICROELEMENTS IN LEAVES OF LINDEN*

Wojciech Dmuchowski[1,2], Aneta H. Baczewska[1], Dariusz Gozdowski[2], Beata Rutkowska[2], Wiesław Szulc[2], Irena Suwara[2], Paulina Brągoszewska[2,3]

[1]Botanical Garden-Center for Conservation of Biological Diversity
Polish Academy of Sciences, Warsaw
[2] Warsaw University of Life Sciences – SGGW, Warsaw
[3]Institute of Environmental Protection – National Research Institute, Warsaw

Abstract

Application of large amounts of NaCl to control slippery roads in winter leads to soil salinity and consequently to ionic imbalances, changes in pH, changes in physicochemical properties of the soil and the death of roadside trees. The aim of this study was to evaluate the effect of salt stress on the content of microelements in the leaves of roadside trees and on the health trees. The subject of research were trees of the Crimean linden (*Tilia* 'Euchlora') growing in the median strip of one of the main streets in Warsaw. The roadside trees contained much higher amounts of Cl and Na than trees in a park (control). There was a significant correlation between the Cl and Na content in leaves of the trees and their health state. As the content of these elements increased, the health condition of leaves clearly deteriorated. There was no significant effect of soil salinity on the micronutrient content in leaves. The content of Cu, Fe, Zn and Mn in linden tree leaves were on levels considered normal, with values not indicative of any deficiency or toxicity. The presence of Fe and Zn in leaves had no significant effect on the health of leaves of the trees. A statistically significant negative relationship was found between the index of leaf damage and their content of Cu and Mn. This means that a higher degree of leaf damage corresponded to a lower content of Cu and Mn. Based on regression analysis, it was estimated an increase in the Cl content in soil solution by approximately 1000 mg dm^{-3} caused an average 0.2% increase in the Cl content in leaves.

Keywords: deicing, urban trees, salt stress, microelements, linden, soil pollution.

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dr hab. Wojciech Dmuchowski, Botanical Garden-Center for Conservation of Biological Diversity, Polish Academy of Sciences, 2 Prawdziwka St., 02-973 Warsaw, Poland, e-mail: w.dmuchowski@obpan.pl

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WPŁYW STRESU SOLNEGO SPOWODOWANEGO ZASOLENIEM GLEBY NA ZAWARTOŚĆ MIKROELEMENTÓW W LIŚCIACH LIP

Abstrakt

Stosowanie dużych ilości NaCl do zwalczania śliskości dróg w okresie zimowym prowadzi do zasolenia gleb, a w konsekwencji do zaburzeń równowagi jonowej, zmian pH oraz zmian właściwości fizykochemicznych gleby i zamierania drzew przyulicznych. Celem badań była ocena wpływu stresu solnego na zawartość mikroelementów w liściach drzew ulicznych i stan zdrowotny drzew. Przedmiotem badań były drzewa lipy krymskiej (*Tilia* Euchlora) rosnące w pasie międzyjezdniowym głównej ulicy w Warszawie. Drzewa uliczne zawierały znacznie więcej Cl i Na niż drzewa z parku (kontrola). Stwierdzono istotne zależności między zawartością Cl i Na w liściach drzew a ich stanem zdrowotnym. Wraz ze wzrostem zawartości tych pierwiastków wyraźnie pogarszał się stan zdrowotny liści. Nie stwierdzono istotnego wpływu zasolenia gleby na zawartość mikroelementów w liściach. Zawartość Cu, Fe, Zn i Mn w liściach lip była na poziomie uznanym za „normalny", nie stwierdzono wartości wskazujących na niedobór lub poziom toksyczny. Zawartość Fe oraz Zn w liściach nie miała istotnego wpływu na stan zdrowotny liści drzew. Stwierdzono natomiast ujemne statystycznie istotne zależności między indeksem uszkodzenia liści a zawartością w nich Cu i Mn. Oznacza to, że wraz ze wzrostem stopnia uszkodzenia liści, zmniejszała się zawartość Cu i Mn. Na podstawie analizy regresji oszacowano w przybliżeniu, że zwiększenie zawartości Cl w roztworze glebowym o 1000 mg dm^{-3} powoduje przeciętne zwiększenie zawartości Cl w liściach o 0,2%.

Słowa kluczowe: stres solny, drzewa miejskie, mikroelementy, zanieczyszczenie gleby, lipy.

INTRODUCTION

Land degradation by salts is a major threat to sustainable crop production in many arid and semi-arid regions of the world (Mavi et al. 2012). In the countries of Northern and Central Europe and in the United States and Canada, we have to deal with soil salinity caused by widespread de-icing of winter streets and sidewalks with salt. NaCl is most commonly used because its inexpensive and effective at de-icing; calcium and magnesium chlorides and calcium and magnesium acetals are applied in smaller amounts (Akbar et al. 2006, Berkheimer, Hanson 2006). According to the United States Geological Survey data, in the U.S., between 9.5 and 20.9 million tons of NaCl were applied on roads annually in 1993-2005 (Sander et al. 2007). In Sweden, 200,000-300,000 tons of NaCl are used on roads every winter (Thunqvist 2004). The dosage of salt per kilometer of a road is 40-80 tons per year (Akbar et al. 2006). For example, in Toronto (Canada) the annual budget for de-icing is $ 50 million (Guthrie 2006). But the hidden costs of de-icing, like corrosion and the environmental damage, are in general much greater than the direct cost of road salting (Fay, Shi 2012).

Of the de-icing salt applied on a road, 20-63% ends up being transported by air and deposited on the ground 2 to 40 m away from the road. At least ninety percent of the total deposition occurs within 20 m (Blomqvist, Johansson 1999, Lax, Peterson 2009). McBean and Al-Nassri (1987) concluded that 90% of the deposited salt was found within 13 m.

It is estimated that over 50% of salt applied on the road permeates into surface water and groundwater. Salt concentration in fresh water bodies may increase up to 30 times compared with unpolluted waters (Ramakrishna, Thunqvist 2004, Viraraghavan 2005, Green et al. 2008, Nowotny et al. 2008).

NaCl applied on roads contributes to soil pollution in the roadside zone, causing a number of adverse changes which lead to soil degradation. The following are examples of adverse changes in soil: alteration in soil structure, decreased soil permeability and aeration, accompanied by increased overland flow, surface runoff and erosion. More intensive erosion results in nutrients and heavy metals being transported from the roadside to surface water. Another possible consequence is the reduction in hydraulic conductivity as pores become blocked by the release of fine particulates and soil colloids, promoting the leaching of base cations and consequently modifying the soil exchange pools. This change affects soil microflora and microfauna communities (Amrhein, Strong 1990, Fritzsche 1992, Defourny 2000, Bergstedt 2001, Norrström, Bergstedt 2001, Bryson, Barker 2002, Green et al. 2008, Nelson et al. 2009, Mavi et al. 2012).

Salt affects trees by inducing water stress, nutrient imbalance and ion toxicity, causing biochemical, anatomical and morphological changes, also making them more susceptible to disease, as a result of which it interferes with their growth and development, and may even cause their death, which is not an uncommon consequence of salt stress to roadside trees (Czerniawska-Kusza et al. 2004*,* Franklin, Zwiazek 2004*,* Dmuchowski et al. 2007, 2011*a*,*b*, Oleksyn et al. 2007, Polanco et al. 2008, Baczewska et al. 2011*a*, Gałuszka et al. 2011, Tahkokorpi et al. 2012).

The aim of this research was to assess the impact of salt stress on the health of roadside trees, and especially on changes in the content of microelements in leaves. The subject of research was the Crimean linden (*Tilia* Euchlora), which is often planted along streets in Warsaw.

MATERIAL AND METHODS

The study focused on the median strip of Żwirki and Wigury Avenue. This is one of the main streets of Warsaw, hence it carries a heavy flow of traffic. The control area was a park located about 150 meters away near the avenue and separated from it by dense hedges of trees and bushes. The top soil on both surfaces was of the same type, described as salty soil. Both areas were populated by Crimean linden (*Tilia* Euchlora) trees about 85 years old.

The soil samples (18) were collected from both surfaces around the selected trees (18). The trees were divided into six categories based on the health status of their leaves. The evaluation of the health of leaves was conducted with a modified method of Duda et. al. (1994). This classification consists of six health categories (the leaf damage index), where 0 meant a healthy tree and 5 is a seriously damaged one (damage of up to 75% of the leaf surface area). The observations of the health were conducted in mid-September 2010. Three trees were selected from each health status category and the control surfaces. Soil samples were taken from the soil under each tree at three locations 1 m away from the trunk. They were collected at three depths (0-20, 20-40, 40-60 cm) with a soil drill. The samples were dried to the air humidity level, ground and passed through a 2 mm mesh sieve.

Air-dry soil samples weighing 100 g were saturated with redistilled water to 150% of full water capacity, and then incubated at room temperature for 66 hours to achieve the ionic equilibrium between the solid and the liquid phases. Soil solutions were obtained from the prepared soil samples by vacuum suction (Wolt, Graveel 1986, Łabętowicz 1995) with a single oil vacuum pump (Dynavac OP4). The solutions were filtered through blotting paper filter into polyethylene bottles, then frozen and stored for chemical analysis.

The following determinations, with three replications, were run on the soil solutions:

- the total content of Zn, Cu, Fe, Mn, Na by atomic emission spectrometry method (ICP-AES, apparatus IRYS Advantage ThermoElementar). The apparatus was calibrated against patterns prepared from Single Element Standards for ICP Solution by UltraScientific. In order to check the calibration curve, the solutions were used to attest the instrument and calibration (QC) at concentrations of 0.1 ppm and 1 ppm before the samples were studied, at every 20 samples against the Combined Quality Control Standard from Ultra Scientific company;
- pH in the fresh soil solutions – with the potentiometric method;
- chlorides – with the flow colorimetric method (a Skalar apparatus).

For the calculations, means from the three sampling sites were used, separately for each tree. The analytic results were obtained in an accredited laboratory, and the accuracy of determinations was ensured by a control system based on the criteria contained in the standard PN-EN ISO/IEC/17025.

The leaf samples used for chemical determination were collected separately from each tree during the last week of July 2011. The leaves were collected from the outer belt of the tree crown – around its fill perimeter at a height of about 4 m. The leaf material was placed in linen bags and dried at 70°C. The dried materials were ground to a powder in a stainless steel impact mill (Fritsch 14702) and stored in tightly sealed plastic containers until the time of analysis. The leaves were washed for one minute in distilled water before they were dried and ground.

For the determination of metals, powdered samples were ashed in a muffle oven (Naberthern L40/11/P320) using the following time/temperature protocol: 120°C – 2h, 200°C – 1h, 300°C – 1h, and 450°C – 5h. The ashes were digested in 30% HCl (Merck suprapure) and filtered through a filter paper (ALLEN et al. 1974). The analyses were performed by flame AAS (Perkin Elmer 1100A), connected to deuterium background correction, hollow cathode lamps and acetylene burner (ROBERTS 1991). Three replicate subsamples of each sample were processed. Three blanks were run with each batch of samples; thus, each sample was blank corrected.

Chloride was determined by the potentiometric titration method using an ion-selective electrode and an Orion Star Plus ion meter (LA CROIX et al. 1970).

For quality control (QC), the elemental content in the plant samples was determined using certified reference materials from the NIST- USA - Apple leaves nr 1515. The results were in good agreement with the certified values. The recovery range was from 90 to 96%.

The means were compared using analysis of variance and the Tukey's procedure of multiple comparisons. Relationships were evaluated using correlations and simple linear regression. The statistical analyses were performed in Statistica 10 (StatSoft) software, with the significance level at 0.05 probability level (SOKAL, ROHLF 1995).

RESULTS AND DISCUSSION

The study included Crimean linden trees, characterized by high sensitivity to street side urban conditions. Just 38% of the trees growing in 1973 along Warsaw's main streets survived until 2008 (DMUCHOWSKI et al. 2011*b*). In Poland, the main cause of roadside trees dying is elevated soil salinity caused by winter deicing of streets and sidewalks (CHMIELEWSKI et al. 1999, BROGOWSKI et al. 2000, CZERNIAWSKA-KUSZA et al. 2004, BACH, PAWŁOWSKA 2006, OLEKSYN et al. 2007, KOCHANOWSKA, KUSZA 2010, WROCHNA et al. 2010, BACZEWSKA et al. 2011a, DMUCHOWSKI et al. 2011a, GAŁUSZKA et al. 2011).

Table 1 shows the results of analyses of soil from three depth levels, including the content of chlorine, metals and soil pH. The pH of surface soil along the street ranged at 7.36-7.52, depending on the depth, and was statistically different from the soil in the park, which was 6.72-7.02. The fact that salinity raises alkalinity of soil has been described in many publications. GAŁUSZKA et al. (2011) determined pH 7.8-8.0 in soil near streets with heavy traffic in Kielce (Poland). In forest soil near a road where deicing was used, ČERNOHLÁVKOVÁ et al. (2008) detected pH 7.6 at a distance of 1 m from the road, 5.5 at 10 m, and just 3.8 in the control soil. Similar results were obtained by GREEN et al. (2008), with 6.7-8.1 pH at 3 m from the main road, and in the control soil 3.8. HOFMAN et al. (2012) studied soil in protected areas near a main road heavily salted in winter (6.6-13 t km^{-1} year^{-1})

Table 1

pH and the average content of particular elements in the three depths of the soil solution

Element	Depth (cm)	Park (control)	Street
pH	0 - 20	7.02*a*	7.52*b*
	20 - 40	6.72*a*	7.36*b*
	40 - 60	6.93*a*	7.38*b*
Cl (mg dm^{-3})	0 - 20	1470*a*	3599*b*
	20 - 40	1304*a*	2561*b*
	40 - 60	1186*a*	2526*b*
Na (mg dm^{-3})	0 - 20	430*a*	2392*b*
	20 - 40	418*a*	1540*b*
	40 - 60	477*a*	1517*b*
Cu (mg dm^{-3})	0 - 20	1.6*a*	1.9*a*
	20 - 40	1.3*a*	1.9*b*
	40 - 60	1.1*a*	1.6*b*
Fe (mg dm^{-3})	0 - 20	5.3*a*	6.7*a*
	20 - 40	4.0*a*	8.3*a*
	40 - 60	2.8*a*	5.7*a*
Mn (mg dm^{-3})	0 - 20	4.5*a*	12.8*b*
	20 - 40	3.7*a*	7.1*a*
	40 - 60	2.4*a*	5.7*b*
Zn (mg dm^{-3})	0 - 20	1.6*a*	2.3*b*
	20 - 40	1.4*a*	2.4*b*
	40 - 60	1.5*a*	2.1*b*

The average values are assigned letters indicating differences between the park and street. The same letter (*a*) stands for a non-significant difference between the means. Different letters (*a* and *b*) stand statistically significantly different means.

where the pH decreased from 7.4-7.8 m to 4.0-4.1in the transect 1-15 m. Similar results were reported by NORRSTRÖM and JACKS (1998) and NORRSTRÖM and BERGSTEDT (2001), BRYSON and BARKER (2002), CZERNIAWSKA-KUSZA et al. (2004), NELSON et al. (2009), KOCHANOWSKA and KUSZA (2010).

Street soils contained more of the analyzed elements than the park soils, and the differences were not statistically significant only in the case of Fe, which could have been due to the very high divergence of results. Particularly large differences occurred for Cl, which – depending on the level - was detected in the concentrations equal 1186-1470 mg dm^{-3} in the park, and 2526-3599 mg dm^{-3} near the street, and for Na, which appeared in the levels of 418-477 mg dm^{-3} and 1517-2392 mg dm^{-3}, respectively.

Leaves from trees growing along the street contained much more Cl and Na than those from the park (control) – Table 2, Figure 1. Leaves from the control trees contained an average of 0.36% Cl and 78.3 mg kg^{-1} Na, and those from the street trees had 0.73-1.92% Cl, and 174-2766 mg kg^{-1} Na. Significant correlations were found between the content of these elements in the leaves and their state of health (Figure 1). With an increase in the content of these elements, the health condition of tree leaves clearly deteriorated. It is accepted that the normal level of Cl in linden leaves should be less than 0.3%, with 0.6-0.8% considered as a threshold value beyond which clear leaf damage appears (Shortle, Rich 1970, Pracz 1978, Pauleit 1988, Dmuchowski, Badurek, 2004, Munck et al. 2010) gives 0.37% as the value of chlorine concentration at which the first faint signs of leaf damage appear. This level was exceeded in leaves of all the street trees studied.

The Na content also significantly affected the health status of leaves. Relatively healthy trees with an index of leaf damage at 0-1 contained 168-174 mg Na kg^{-1}, while badly damaged ones, indexed at 4-5, had 1338-2766 mg Na kg^{-1}. It is not easy to interpret the results of the sodium content in leaves because the literature does not provide us with any information about toxicity limits. There is only one report, by Munck et al. (2010), in which > 650 mg kg^{-1} is said to be the limit value beyond which tree leaves contain distinctly fewer ions. Sodium is characterized by high lability both in soil and plants, and its excess causes mainly ionic imbalance, rather than a simple toxic effect (Alaoui-Sosse 1998, Dmuchowski et al. 2011*a*).

The content of Cu, Fe, Zn and Mn in the linden leaves was on levels considered normal, with values not indicative of any deficiency or toxicity. A normal level for Cu has been determined at 2-20 mg kg^{-1} and toxic levels are above 30 mg kg^{-1} (Hewitt, Smith 1974, Kabata-Pendias, Pendias 2001). Madejon et al. (2006) determined as the normal Mn content in leaves of *Quercus* at 17 mg kg^{-1}, while Kabata-Pendias and Pendias (2001) identified 10-25 mg kg^{-1} as sufficient for most plants. Smitd (1988) concluded that a normal level of Zn in tree leaves was 25-80 mg kg^{-1}, but Kabata-Pendias and Pendias (2001) claimed it was 10-100 mg kg^{-1}, although all these researchers stated that values above 100 mg kg^{-1} were toxic. Linzon et al. (1976) found 250 mg kg^{-1} as a limiting toxic level of Zn for deciduous trees. No values were found in the literature for deficient and toxic levels of iron in leaves of trees.

Table 2

The average content of elements in linden leaves, depending on the leaf damage index

Element	Leaf damage index						
	control	0	1	2	3	4	5
Cl (%)	0.36*a*	0.73*ab*	0.78*ab*	1.25*bc*	1.64*cd*	1.77*cd*	1.92*d*
Na (mg kg^{-1})	78*a*	174*a*	168*a*	198*a*	353*a*	1338*ab*	2766*b*
Cu (mg kg^{-1})	10.61*ab*	14.8*b*	13.9*b*	12.4*ab*	10.4*ab*	10.5*ab*	9.4*a*
Zn (mg kg^{-1})	29.1*a*	27.3*a*	29.6*a*	26.8*a*	24.3*a*	26.6*a*	24.4*a*
Fe (mg kg^{-1})	163*a*	311*a*	308*a*	286*a*	251*a*	292*a*	256*a*
Mn (mg kg^{-1})	49.6*a*	92.6*a*	74.9*a*	66.5*a*	47.7*a*	48.3*a*	42.9*a*

The means are assigned letters indicating homogeneous groups. If the letter is the same, the difference between the means is not statistically significant. If the letters are different, then the two means differ statistically significantly.

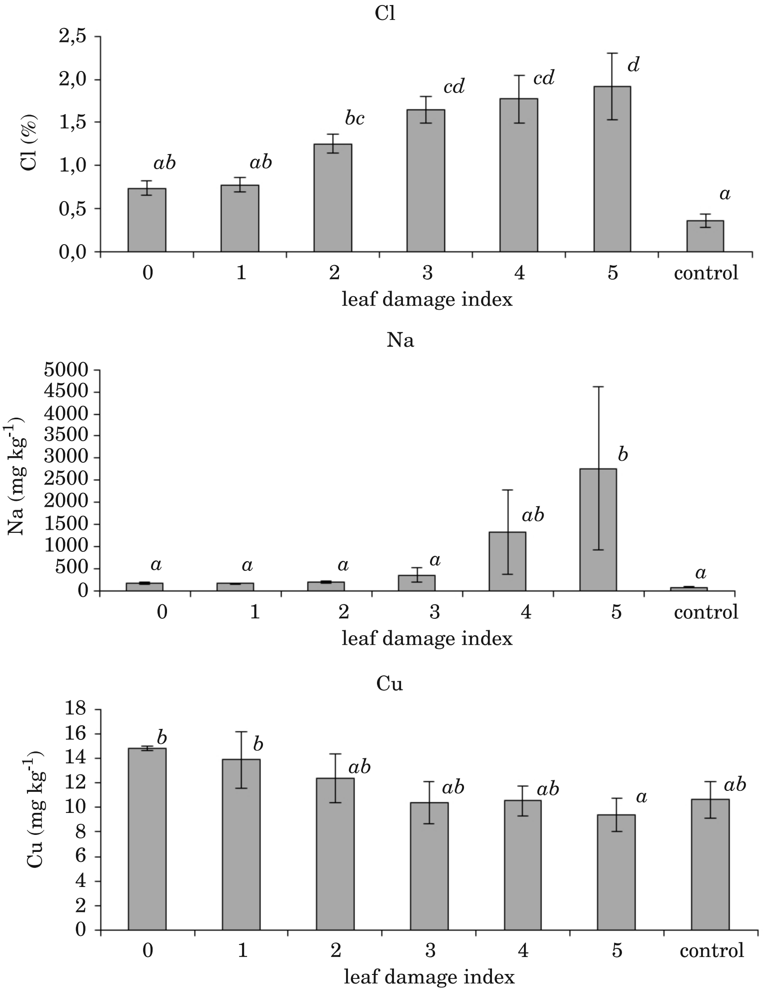

Fig. 1. The average content of Cl, Na and Cu in the leaves, depending on the leaf damage index
Error bars present values of standard deviations (SD) and letters indicate homogenous groups of means (if there is even one common letter, then the difference between the means is not statistically significant)

Iron and zinc in leaves had no significant effect on the health of linden leaves (Table 3). A statistically significant negative relationship was found between the leaf damage index and the content of Cu and Mn. Thus, a higher degree of leaf damage or a worse health status were correlated with the Cu and Mn content in leaves. In all the examined trees, the Cu and Mn content did not appear deficient, hence the above dependence may have been caused by an ionic imbalance due to the high content of Cl and Na in leaves. Baczewska et al. (2011*a*) and Dmuchowski et al. (2011a) demonstrated

Table 3

Correlation coefficients between pH and the content of elements in the soil solution versus their leaf content and the leaf damage index

Element	Depth (cm)	Leaf damage index	Cl	Na	Cu	Zn	Fe	Mn
		-	0.91**	0.69**	0.81**	-0.30	-0.34	-0.49*
pH	0-20	0.22	0.26	0.32*	-0.26	0.00	-0.16	-0.08
	20-40	0.17	0.20	0.21	-0.20	-0.34*	-0.14	-0.47**
	40-60	0.05	0.07	-0.10	-0.08	-0.22	-0.04	-0.31*
Cl	0-20	0.40**	0.44**	0.46**	-0.21	-0.09	0.03	-0.20
	20-40	0.38**	0.43**	0.47**	-0.27*	-0.32*	-0.11	-0.30*
	40-60	0.21	0.25	0.53**	-0.14	-0.25	-0.08	-0.31*
Na	0-20	0.42**	0.44**	0.60**	-0.29*	-0.27	-0.04	-0.24
	20-40	0.36**	0.42**	0.61**	-0.23	-0.26	-0.03	-0.27
	40-60	0.44**	0.43**	0.51**	-0.26	-0.11	-0.02	-0.22
Cu	0-20	0.24	0.23	0.34*	-0.08	0.01	0.06	-0.24
	20-40	-0.03	-0.08	0.04	0.02	0.01	0.11	0.11
	40-60	0.05	0.10	-0.12	-0.18	0.19	-0.14	-0.06
Fe	0-20	0.06	0.19	0.06	-0.12	-0.18	-0.05	-0.13
	20-40	-0.20	-0.26	-0.16	0.23	0.18	0.12	0.35*
	40-60	-0.19	-0.05	-0.14	0.13	0.16	0.05	0.21
Mn	0-20	-0.21	-0.12	0.01	0.28*	0.04	0.23	0.16
	20-40	-0.10	-0.19	-0.12	0.14	0.27*	0.09	0.42**
	40-60	-0.14	-0.11	0.02	0.18	0.23	0.05	0.21
Zn	0-20	0.08	0.15	0.10	0.05	-0.01	0.15	0.00
	20-40	0.15	0.06	0.11	-0.06	0.14	0.11	0.01
	40-60	0.01	0.01	0.08	0.04	0.17	0.09	0.02

* Statistically significant correlations at the level of $P<0.05$

** Statistically significant correlations at the level of $P<0.01$

that the ionic imbalance caused by soil salinity resulted in a high negative correlation coefficient, indicating that an increasing content of primary macronutrients, such as nitrogen, phosphorus, potassium and sulfur, in leaves was correlated with a better health status of street trees.

Many studies suggest that small amounts of trace elements are dissolved in the soil solution and may be translocated to subsoil horizons. The most important chemical process that affects the solubility and mobility of trace elements is their sorption onto soil solid phases. Metal sorption depends, *inter alia*, on the nature of organic and inorganic soil constituents, as well as soil pH. The soil pH is the main factor which controls the solubility, mobility and transport of trace elements in a soil profile. Metal solubility and mobility decrease under a higher soil pH. The soil organic matter content is the second most important factor affecting the mobility of trace elements in the soil solution. An increase in the soil DOM concentration leading to the formation of organic and trace elements complexes may enhance the downward transport of these elements in a soil profile (Silvana, Rodrigo 2012). The vertical distribution of copper in the soil solution depends on the content of soil organic matter. Organic complexes of copper accounted for more than 90% of the copper solution in the surface horizon. This process of forming complexes increases the concentration of Cu in the mobile phase, which promotes Cu transport over long distance. The copper vertical distribution in the soil solution is associated with the total organic carbon and soil solution pH. Fulvic acids are the main organic compounds responsible for Cu mobility. The mobility of TOC and Cu is the lowest in a strongly acid soil solution but higher in a soil solution with neutral reaction. This suggests that Cu can be transported downward in a soil profile to the the 60-120 cm layer, which acted like a barrier to a further downward transport (Altaher et al. 2011).

The solubility and mobility of manganese, zinc and iron are generally low under a high pH and high organic matter content. The mobility of these elements in the soil solution of acid soils with a low organic matter content is high (Violante et al. 2010).

Beesley et al. (2010) showed that Zn can be transported downward in a soil profile (70-100 cm). The peak concentration of Zn in the soil solution was recorded at a 50 cm depth. There was no correlation between Zn and DOC in the soil solution.

Based on the correlation analysis, relationships were determined between elemental concentrations in the soil solution, and their content in leaves of linden trees (Figure 2). For most elements, there was no distinct, statistically significant correlation. The only positive correlation was found between the concentrations of Na and Cl in the soil versus the content of these elements in leaves. Alfani et al. (1996), who studied urban trees of the species *Quercus ilex,* found no correlation between the content of metals (Cu, Fe, Mn) in the soil and in tree leaves. The authors attributed this finding to high levels of airborne metals accumulated by leaves. The positive correlations were found only for Pb. Łukasik et al. (2002) also failed to verify a statistically significant relationship between concentration of metals (Pb, Cd, Zn) in the soil and their content in leaves of urban trees and shrubs (*Acer, Robinia, Symphoricarpos, Ligustrum*). The lack of statistical significance between soil and leaf content of metals was also reported by Samecka-Cymarman and Kempers (1999), who studied Zn and Pb in leaves of *Ilex aquafolium, Mahonia aquifolium* and *Rhododendron catawbiense*.

The regression analysis (Figure 2) revealed a relationships between the content of Na and Cl in the soil solution and in leaves. The regression

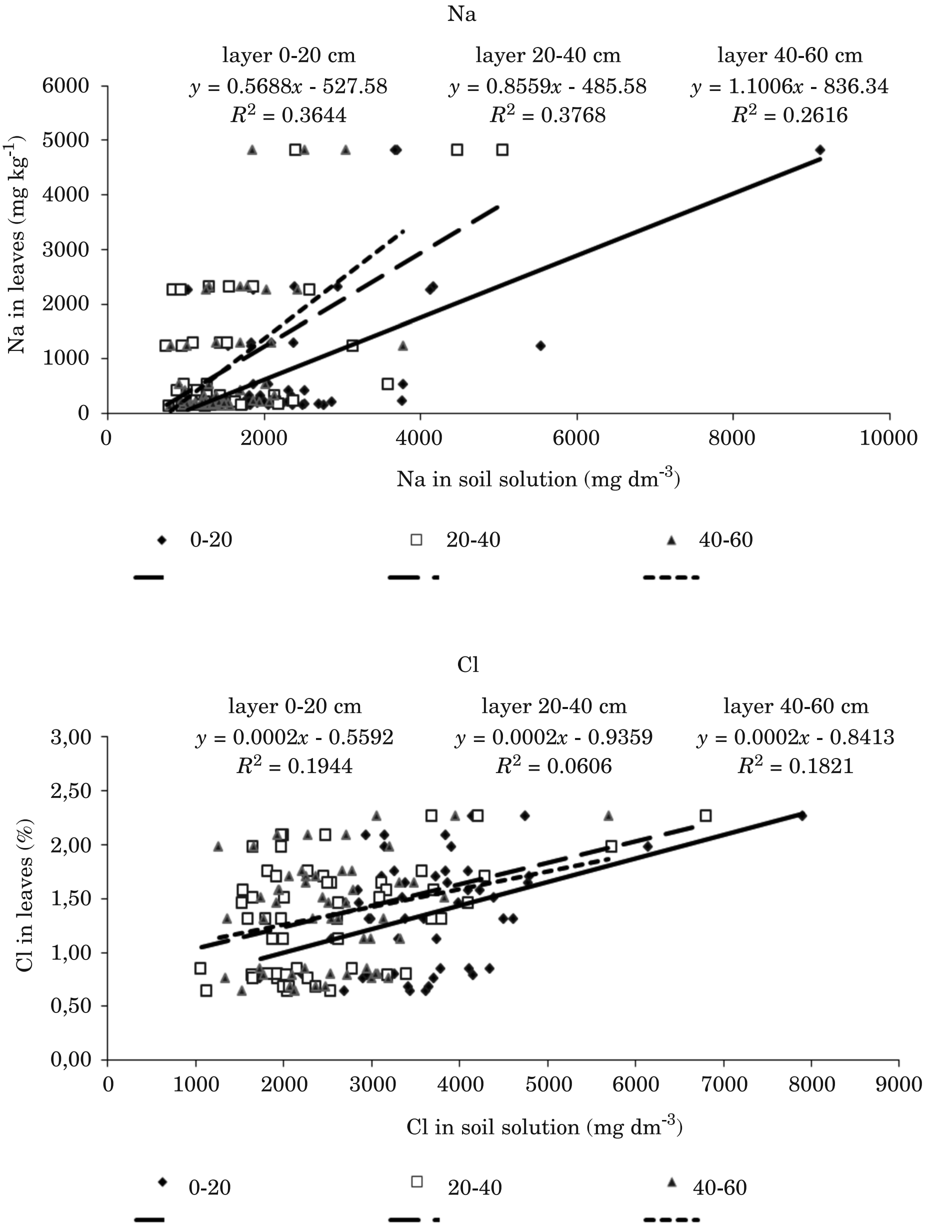

Fig. 2. Regressions between the content of Na and Cl in the soil solution and in leaves for different soil layers

function enabled us to estimate the content of Na and Cl in leaves, given the specific content of these elements in the soil on different levels. In the case of Cl, all regression functions are similar in the form, hence we can estimate that an increase in Cl in the soil solution by 1000 mg dm^{-3} caused an average increase of the Cl content in leaves by 0.2%. Regarding sodium, the regression functions for different Na levels in soil assumed different shapes, while demonstrating a similar power of the relationship between the content of Na in the soil and in leaves.

CONCLUSIONS

1. The soil from street side surface contained statistically significantly more Cl, Na, Cu, Fe, Zn and Mn than the park soil. Particularly large differences occurred in the contents of Cl and Na resulting from de-icing of the roads. The soil salinity also caused increase in soil alkalinity.

2. The street trees contained much higher amounts of Cl and Na than the park trees. Significant correlations were found between the content of Cl and Na in the leaves of trees and their state of health. With the increase in the content of these elements, the health condition of the leaves clearly deteriorated.

3. The content of Cu, Fe, Zn and Mn in the leaves of linden were at levels considered “normal”, no values were found to be indicative of a deficiency or toxic levels. The level of Fe and Zn in the leaves had no significant effect on the health of the trees. A statistically significant negative correlation was found between the index of leaf damage, and their content of Cu and Mn. This means that with an increase in the degree of leaf damage, the content of Cu and Mn decreased.

4. A positive correlation was found between Na and Cl content in the soil, and the content of these elements in the leaves. In the case of Cu, Zn, Fe and Mn., there were no clear statistically significant dependencies between their concentration in the soil, and the content in the leaves.

5. Based on regression analysis it was estimated that increasing the Cl content in the soil solution by 1000 mg·dm^{-3} causes an average increase in the leaf Cl content of approximately 0.2%.

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