Short Communication

Evaluation of Vigour and Health of 'Street' Trees Using Foliar Ionic Status

Wojciech Dmuchowski[1, 2]*, Zygmunt Brogowski[2], Aneta Helena Baczewska[1]

[1]Botanical Garden-Center for Conservation of Biological Diversity, Polish Academy of Science, Prawdziwka 2, 02-973 Warszawa, Poland
[2]Faculty of Agriculture and Biology, Warsaw University of Life Sciences-SGGW, Nowoursynowska 159, 02-776 Warszawa, Poland

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Abstract

Street-side trees in cities are characterized by poor health, with high salinity and pH, that leads to an early death. The main reason is soil salinity caused by winter road maintenance using salt (NaCl). Our research comprised three species of trees. A dependency was determined between their vigour and health and the content of biogenic elements, typical pollution, and indicators of ionic balance. It was demonstrated that disturbances of ionic balance had a negative effect on the health of leaves and trees. Increasing the amounts of chlorine and sodium in the leaves did not have any influence on the content of phosphorus, potassium, nitrogen, and sulphur. The content of calcium was slightly lowered, and that of magnesium was lowered to a large extent. The leaves containing over 15% chlorine in the sum of all elements studied, expressed in equivalent values, were characterized by noticeable disturbances in their growth and health.

Keywords: city environment, deicing, tree decline, ionic balance, salt stress

Introduction

Many elements of an urban environment have a negative influence on the vigour and health of trees, leading in many cases to their gradual dying off. Street-side trees are considered especially endangered. The vigour and health of trees in the cities of northern Europe and North America are poor, resulting in massive die-offs. In the cities of Western Europe, over 700,000 trees die annually [1]. In Warsaw, during 1973-2000 over 50% of trees growing alongside the four main thoroughfares in the center of the city were removed [2].

The chemical technology used in the removal of snow and ice from roads and sidewalks, relying primarily on the application of sodium chloride (NaCl), is considered the main cause for deaths of city trees [3-11].

Excess NaCl negatively affects almost all the processes taking place in plants. It interacts toxically and electrochemically on the molecular, cellular, and tissue levels. However, the disturbance of ionic balance is considered to be the main reason for the worsening state of tree health, and for their deaths [7, 12-21]. The goal of our study was to determine the salt stress influence on the disturbance of ionic balance as the fundamental cause of deterioration of vigor and health of the trees.

Materials and Methods

The research site was John Paul II Avenue, a wide thoroughfare in the center of Warsaw, and one of its main streets. Research on the state of health of trees growing at this location was conducted from 1973 to 2007 by Dmuchowski et al. [6]. Based on the conducted inventory counts, it was determined that in the span of 34 years the

*e-mail: dmuchowski@ob.neostrada.pl

Table 1. H_2O-soluble cations and anions as well as pH indicator and electrical conductivity of the soils from John Paul II Avenue.

Tree species	Number of tree	Download sample depth (cm)	mg/100g d.m.*							cations/ anions	pH in KCl	Electricical conductivity (ms/m)
			Ca	Mg	K	Na	Cl	SO_4	NO_3			
Warsaw Linden	2	0-25	260	6.4	42.6	20.6	8.4	5.8	8.3	18.1	7.6	14.6
		25-50	382	5.4	22.6	17.0	9.0	5.9	1.2	26.5	7.8	1.9
	11	0-25	340	4.0	16.4	120.0	128.0	14.5	7.5	3.2	7.9	61.2
		25-50	514	3.2	16.2	96.6	96.4	6.4	0.7	6.1	8.1	45.7
Crimean Linden	38	0-25	320	2.5	10.2	7.9	1.4	3.4	0.8	61.5	8.1	8.4
		25-50	102	2.4	5.2	7.5	2.6	1.3	1.4	22.1	7.4	6.7
	40	0-25	480	3.2	10.4	94.0	77.9	5.0	1.4	7.0	8.0	39.3
		25-50	518	2.4	14.8	83.0	87.7	7.8	1.1	6.4	8.1	45.6
Silver Maple	84	0-25	384	4.2	18.6	28.4	24.0	3.5	5.7	13.1	7.9	19.8
		25-50	520	4.6	18.2	33.8	31.3	3.8	3.7	14.5	8.0	21.0

* Exchangeable cations extracted with 1 m ammonium acetate, pH=7.0.

number of trees growing at John Paul II Avenue decreased by 46%. The greatest losses (94%) were observed in the case of the European Rowan (*Sorbus aucuparia* L.).

The trees, planted on both sides of John Paul II Avenue, were of poor vigour and health. The following 23 trees growing immediately adjacent to the street were selected for research: 5 Warsaw Linden (*Tilia tomentosa* 'Varsoviensis'), 10 Crimean Linden (*Tilia* 'Euchlora') and 8 Silver Maple (*Acer saccharinum* L.). The state of health of the trees was evaluated based on the degree of leaf damage. The leaves were evaluated using a seven-degree scale: from 0 for the undamaged leaves to 6 for trees in a leafless state. The time chosen for observation was the middle of September, because differences in the extent of leaf damage are greatest at that time of year, making it easier to interpret the results.

Analysis of the soils was done in two replicants according to the accepted methods applied in soil science. The chemical reaction indicators of exchangeable cations and anions, as well as electrical conductivity, were measured at two horisons: 0-25 cm and 25-50 cm, i.e. in the zone of the greatest presence of roots of the studied trees (Table 1).

Leaves for analysis were collected from the selected trees in the middle of July. They were collected from the outer parts of the upper branches of the trees – along the full perimeter at heights from 2 m to 4 m. The leaf samples were not washed after collection. In determining the macro elements, no washing is applied because some of them, like potassium, and to a lesser degree sodium and chlorine, could be washed away, thus distorting the results. The leaves were dried at 70ºC and then ground, and the elements were determined (Table 2) using the following methods:

- phosphorus (P) as well as: magnesium (Mg), calcium (Ca), potassium (K), and sodium (Na) were determined after dry mineralization in a muffle oven [22], by the method of atomic spectrophotometry using a Perkin Elmer apparatus 1100B [23, 24];
- chlorine (Cl) by using the method of potentiometric titration with the application of an ion-selective electrode and an ions meter Orion type 701a [25];
- sulphur (S) was determined using a LECO 132 apparatus [26];
- the sum of organic acids ($R\text{-}COO^-$) was computed using the method proposed by Van Tuil et al. [27] and De Wit et al. [28] from the difference between the sum of cations and the sum of anions expressed in equivalent values, in meq/100g of dry leaf mass according to the formula:

$$R\text{-}COO^- = (\Sigma_K - \Sigma_A)$$

sum of cations $\Sigma_K = Ca^{2+} + Mg^{2+} + K^+ + Na^+$
sum of anions $\Sigma_A = H_2PO_4^- + SO_4^{2-} + Cl^- + NO_3^-$

The content of nitrogen (N) was omitted in the calculations because of the presence of trace amounts of nitrates (NO_3^-) in the soil (<2 mg/100 g) and in the leaves of trees.

The contents of ingredients in the leaves were converted into equivalent values (meq/100 g) by dividing the results obtained per unit mass by atomic weight and valence. The values thus calculated allow one to compute the state of balance in the plants, and therefore the comparison of electrochemically equivalent data, as the plants get their nutrients using the mechanism of equivalent exchange. For example, for the received Ca^{2+} the plants return to the soil environment $2H^+$, and for receiving, for example $H_2PO_4^-$ they return HCO_3^-, etc.

Results and Discussion

Soils from the studied site, of an anthropogenic character, demonstrated alkaline reaction due to amounts of salt (NaCl), as well as great abundance of exchangeable Ca, K, and Na.

Table 2. The content of cations and nitrogen in the leaves of trees at John Paul II Avenue in Warsaw.

Tree species	Number of tree	Leaf damage index	meq/100g d.m.										
			Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	(Ca+Mg)	(K+Na)	∑Cations	$\frac{(Ca+Mg)}{(K+Na)}$	N	$\frac{N}{\sum Cations}$	$\frac{N^*}{\sum K+\sum A\min}$
Warsaw Linden	1	1	52.2	24.5	48.8	1.0	76.7	49.8	126.5	1.5	202.7	1.60	1.29
	2	3	41.4	20.6	31.2	2.8	62.0	34.0	96.0	1.8	186.3	1.94	1.19
	5	2	50.6	25.1	40.9	1.3	75.7	42.2	117.9	1.8	173.4	1.47	1.04
	11	1	51.7	23.4	42.5	0.9	75.1	43.4	118.5	1.7	184.9	1.56	1.18
	13	3	42.7	20.6	37.1	1.9	63.3	39.0	102.3	1.6	165.6	1.62	1.04
Crimean Linden	16	3	44.8	13.7	33.0	2.4	58.5	35.4	96.9	1.7	163.5	1.68	1.12
	18	3	46.0	11.4	35.8	5.4	57.5	41.2	98.7	1.4	179.2	1.81	1.23
	21	5	35.0	10.2	31.5	15.9	45.2	47.4	92.6	1.0	169.9	1.83	0.95
	22	5	34.5	10.4	30.2	12.9	44.9	43.1	88.0	1.0	158.5	1.80	0.95
	23	2	41.4	11.4	34.3	0.9	52.8	35.2	88.0	1.5	152.7	1.73	1.16
	24	2	44.0	13.1	38.9	0.9	57.1	39.8	96.9	1.4	168.5	1.74	1.18
	26	1	45.8	20.9	34.5	1.2	66.7	35.7	102.4	1.9	154.2	1.50	1.04
	31	1	46.3	18.8	34.8	0.7	65.1	35.5	100.6	1.8	156.3	1.55	1.10
	38	2	54.2	20.3	40.9	1.3	74.5	42.2	116.7	1.8	167.0	1.43	0.98
	40	5	34.0	10.8	28.4	7.7	44.8	36.1	80.9	1.2	150.6	1.86	1.04
Silver Maple	52	1	32.7	12.9	38.9	0.4	45.6	39.3	84.9	1.2	152.0	1.79	1.37
	53	2	32.0	10.6	41.7	0.5	42.6	42.2	84.8	1.0	149.9	1.71	1.20
	55	2	23.5	11.0	39.1	0.4	34.5	39.5	74.0	0.9	151.3	2.04	1.37
	57	2	27.6	13.4	35.3	0.4	41.0	35.7	76.7	1.1	147.0	1.91	1.29
	61	2	28.4	13.1	38.4	0.3	41.5	38.7	80.2	1.1	160.6	2.00	1.33
	65	2	28.4	11.5	42.2	0.3	39.9	42.5	82.4	0.9	154.9	1.88	1.33
	80	6	31.7	7.6	33.2	0.6	39.3	33.8	73.1	1.2	139.9	1.91	1.10
	84	6	29.4	8.9	31.2	1.0	38.3	32.2	70.5	1.2	155.6	2.20	1.21

* The ratio N to the sum of cations+mineral anions.

High Cl content was affirmed in a majority of the studied points: on the other hand there were very small amounts of exchangeable Mg and NO_3^- (Table 1). The poor state of health of the studied trees could be the result of, among other things, a deficit of Mg and N, and an excess of Cl.

High pH of saline soils is a natural phenomenon and occurs both in natural as well as in anthropogenic soils. Alkalization of saline urban soils is described in many publications [5, 15, 29-32]. An additional factor present in Warsaw is the pollution of air with alkaline dust, and the fact that the city, having been completely destroyed during World War II, was re-built literally on top of the rubble, which contributed to additional alkalization of soils.

In all analyzed samples the level of chlorine present in the leaves was higher than 0.6%, which is considered a toxic level for linden and maples [33-35]. The content of macro elements in the leaves of studied trees was differentiated but in no case did it reach a value considered deficient. And thus for nitrogen the deficit level was 1.7-2.1% [36, 37], with the lowest result for maple leaves at 2.3%. A similar situation occurred in the case of other macro elements studied: deficit level of calcium is 0.50% [37-39], in the leaves of studied trees the minimum 0.89%, magnesium deficit 600 mg/kg [37, 38, 40], in the leaves 860 mg/kg, the deficit level of potassium 0.55% [39-42], and in the leaves 1.10%, the deficit level of phosphorous 0.10% [37, 38, 42], and in the leaves the minimum 0.26%.

Ion state of leaves of the studied species of trees was diversified. The linden with leaves in a poor state of health contained less Ca than those relatively healthier. The Warsaw Linden of damage index at 3 contained 20% less Ca than the less damaged trees. However, the Crimean Linden of leaf damage index at 5 contained about 25% less Ca than the trees of damage index at 1-3. No relationship was found between the content of Ca in the leaves of the Silver Maple and their state of health.

Among the cations in the leaves of linden the dominant one was clearly Ca, and the content of cations would be arranged according to a decreasing series:

$$Ca > K > Mg > Na$$

However, in the leaves of the Silver Maple the content of Ca ranked in second place according to the decreasing series:

$$K > Ca > Mg > Na$$

The share of Ca in the sum of alkaline cations varied in the range 30-43%. However, its share in the sum of all studied macro ingredients was contained in the range 11-14%.

The demand for Mg by the studied trees was strongly differentiated. The leaves of the Warsaw Linden contained on average 22.8 meq/100g, of the Crimean Linden by about 40% less, and of the Silver Maple even about 50% less. The percentage share of Mg in the sum of all mineral ingredients of interest in the studied leaves ranged from 2.8 to 6.8%. The lowest was in the maple (on the average 4.1%), slightly higher in the Crimean Linden (on the average 4.5%), and the highest in the Warsaw Linden (on the average 6.7%).

We observed a noticeable influence of Cl on the content of Mg in the leaves. In all the trees in which the content of Cl in the leaves exceeded 40 meq/100g, the content of Mg was clearly lower. If the percentage share of Cl in the sum of all mineral ingredients exceeded 15%, the content of Mg was lowered by about one third, and in some cases by half. One should suppose that the interaction between these two elements could cause yellowing and drying off of leaves in the studied trees as early as in early summer. Maybe it was the deficit of Mg in the leaf tissue that had made the synthesis of chlorophyll more difficult.

The share of K among the alkaline cations in the leaves of the studied trees was significant. Its content was slightly lower than the content of Ca in both species of linden. However, in the Silver Maple it was the dominant element among the alkaline cations (Table 2, Fig. 1). Its percentage share among the alkaline cations in the leaves of linden ranged from 32.5 to 40.0%, and in the Silver Maple its share was significantly higher and ranged from 44 to 53%. The state of health of the trees (leaf damage index) had no relationship to the content of K.

Sodium in the leaves of the studied trees was present in much lesser amounts than the remaining alkaline cations

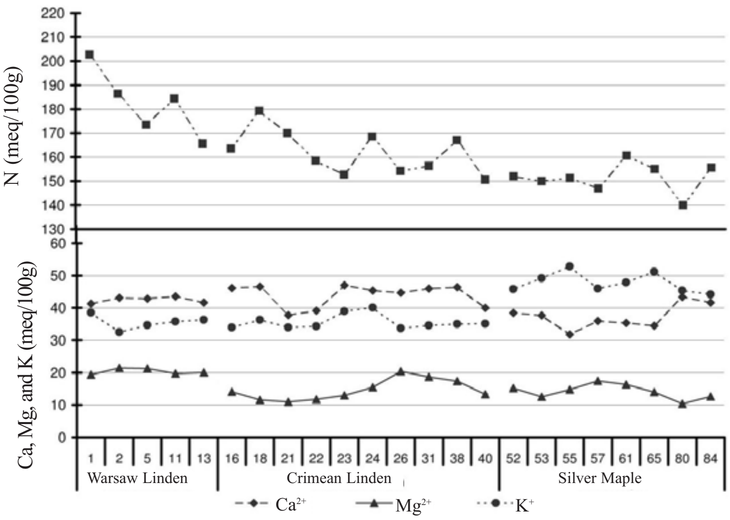

Fig. 1. The content of cations and nitrogen in the leaves of trees from John Paul II Avenue (equivalent values – meq/100g).

Table 3. The content of mineral anions and organic acids in the leaves of trees at John Paul II Avenue in Warsaw.

Tree species	Number of tree	meq/100g d.m.					
		Cl^-	SO_4^{2-}	$H_2PO_4^-$	$\sum$Anions	R-COO$^-$	$\frac{R-COO^-}{\sum Anions}$
Warsaw linden	1	23.5	3.4	3.7	30.6	95.9	3.1
	2	53.4	3.8	3.0	60.2	35.8	0.6
	5	42.5	3.5	3.3	49.3	68.6	1.4
	11	30.3	3.9	3.5	37.7	80.8	2.1
	13	49.7	4.0	3.1	56.8	45.5	0.8
Crimean Linden	16	41.3	4.2	3.1	48.6	48.3	1.0
	18	39.2	4.7	3.2	47.1	51.6	1.1
	21	78.4	4.3	2.9	85.6	7.0	0.1
	22	67.1	4.7	3.2	75.0	13.0	0.2
	23	35.3	4.5	3.8	43.6	44.4	1.0
	24	38.3	4.3	3.7	46.3	50.6	1.1
	26	37.9	4.0	3.4	45.3	57.1	1.3
	31	33.6	4.1	3.8	41.5	59.1	1.4
	38	45.1	4.0	3.7	52.8	63.9	1.2
	40	56.1	4.1	2.8	63.0	17.9	0.3
Silver Maple	52	18.7	4.2	3.5	26.4	58.5	2.2
	53	33.0	4.1	3.4	40.5	47.3	1.2
	55	28.8	3.6	3.8	36.2	37.8	1.0
	57	29.4	4.3	3.2	36.9	39.8	1.1
	61	32.4	4.1	3.6	40.1	40.1	1.0
	65	26.1	4.5	3.4	34.0	48.4	1.4
	80	46.6	4.6	2.9	54.1	19.0	0.3
	84	50.6	4.3	3.0	57.9	12.6	0.2

(Table 2, Fig. 1). The linden with significantly damaged leaves contained greater amounts of this element. This dependency was not observed in the case of the Silver Maple. The percentage share of Na among the alkaline cations did not exceed one percent, with the exception of trees with significantly damaged leaves.

In all studied trees the leaves contained more bivalent than monovalent cations: the Warsaw Linden averaged about 40% more and the Crimean Linden about 30%, but in the Silver Maple the content of these two groups of cations was almost balanced. It should be noted that each kind and group of plants possesses a defined ratio of bivalent and monovalent cations. Monocotyledonous plants show domination of monovalent cations over the bivalent. Dicotyledonous plants and trees mostly have a domination of bivalent cations over the monovalent ones. If such a balance is disturbed, plant growth is reduced or stunted [27, 28].

According to Mattson [43] the differences in the intake of monovalent and bivalent cations lie in the sorption capacity of roots. Plants with low sorption capacity of roots (monocotyledonous) absorb monovalent cations, but dicotyledonous with a higher sorption capacity of roots absorb mostly predominantly bivalent cations. Maybe the maple belongs to a group of plants with a lower sorption capacity of the root system in comparison to the linden and therefore both groups of cations were absorbed from the soil in similar quantities.

The content of Cl in the leaves was the highest among mineral anions. In the leaves of the Warsaw Linden it comprised on the average about 80% of the sum of anions, of the Crimean Linden on average 86%, and of the Silver Maple on average about 68%. It was affirmed that the trees with the leaf damage index at 4-5 contained about 40% more chlorine than those with the value of the index at 1-2. Chlorine as an anion neutralizes positive charge in plants, and plants are forced to reduce production of organic acids in order to maintain electrochemical balance within the plant tissues. The low content of organic acids in turn limits the plant's ability to produce carbohydrates, amino acids, proteins, and other compounds. This further results in slowing down the plant growth rate, and lowers biomass production. Its visible result is the reduction of annual tree rings [4, 5, 13, 27, 28].

The content of S and P in the leaves was relatively little differentiated. There was no dependency found between the state of health of the trees and their content in the leaves. The content of particular anions SO_4 and H_2PO_4 did not exceed 5 meq/100g of the dry leaf mass. Both of these ingredients comprised only from 2 to 3% in the balance of all mineral ingredients being determined (cations+anions).

Among mineral anions the decreasing series of their content in the leaves of the studied trees was as follows:

$$Cl\ (40.6) > SO_4\ (4.1) > H_2PO_4\ (3.3)$$

The content of Cl was higher than the contents of sulphates and phosphates by about tenfold. Chlorine, and likewise sodium and potassium, do not form connections with organic compounds in plants.

The level of organic acids in the leaves was diversified. A higher value of the leaf damage index was accompanied by lower content of organic acids. It seems that the ratio of the sum of organic anions to the sum of mineral anions may be a good indicator of the state of health of the street-side trees in the cities. All the trees with damage index at 3 and higher were characterized by a ratio much lower than one. The relatively healthy trees had this ratio significantly higher than one. A high damage index of the studied trees fully corresponded with the minimal content of organic acids. Also, the measured increment of the tree circumference during the period of the last four years pointed to evident dependency on the level of organic acids in the leaves (Fig. 2).

The trees showing damage index at 5 (the Crimean Linden) demonstrated minimal increase in tree stump thickness, which points to their dying off. However, the Silver Maple in a similarly poor state of health demonstrated a small increase (Fig. 2). Probably this species is capable of self regeneration even though the content of mineral anions manifold outnumbered the content of organic acids (Table 3 and Fig. 2). In all studied cases, independent of the species, the trees with the highest content of organic acids were relatively healthy (leaf damage index 1, Fig. 2). At the same time, in these cases the lowest total content of mineral anions was observed.

Nitrogen in this study was not included in any of the discussed groups of element cations – anions for the reason that it is absorbed by the plants from the soil both in the anion form NO_3^- and in the cation form NH_4^+. Free ions of this element are quickly built into the plant amino acids and proteins.

Nitrogen comprised the dominant element among all biogens utilized by the plants. Its quantities exceeded the sum of cations and anions (Table 3). The ratio of the content of nitrogen to the sum of mineral ions ($N/\sum K + \sum An.min$) only in a few cases was lower than one. This concerned the trees with significantly damaged leaves. One should underline that the percentage share of N in the studied leaves compared to all mineral elements ranged on average from 51.8 to 56.0%. The remaining seven mineral elements comprised less than half of the biogens absorbed from the soil by the studied trees.

Research showed a dependency between the state of health of the trees and the ion composition of their leaves. The leaves of Warsaw Linden in a poor state of health (leaf damage index 4-5) demonstrated the following series with decreasing content of elements being determined:

$$N > Cl > Ca > K > Mg > S >> P > Na$$

For trees with lesser damages (leaf damage index 1-2) the series was as follows:

$$N > Ca > K > Mg > Cl > S > P > Na$$

By analogy the quantitative arrangement of ingredients in the leaves of the highly damaged Crimean Linden decreased according to the following series:

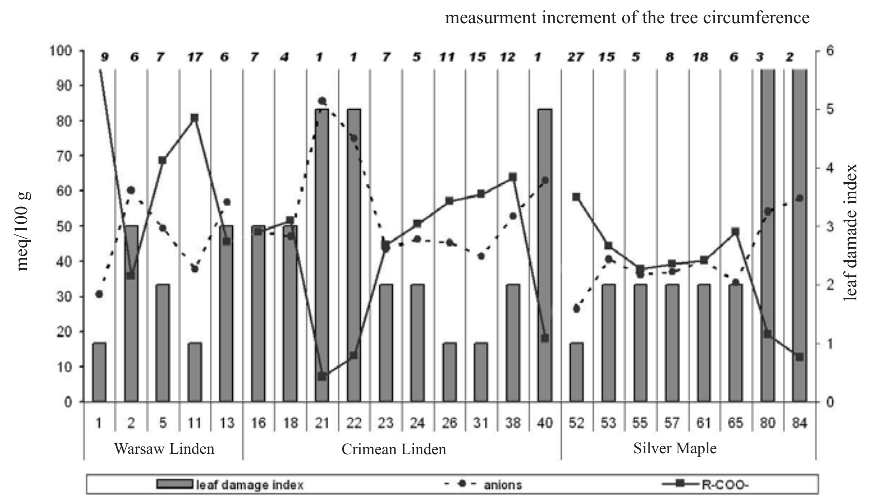

Fig. 2. Comparison of the state of health of trees with the content of the elements in the leaves (equivalent values – meq/100g) as well as the increment of tree stump thickness (during the last four years).

$$N > Cl > Ca > K > Na > Mg > S > P$$

However, the series for the slightly damaged trees was as follows:

$$N > Ca > Cl > K > Mg > S > P > Na$$

The Silver Maple demonstrated identical series of the content of elements as the Crimean Linden.

Conclusions

1. It was affirmed that the state of health of trees is a reflection of the ion state of leaves. Disturbing the state of ionic balance leads to greater or smaller damage to the trees.
2. The content of chlorine in the leaves with a greater than 15% share in the sum of all the studied elements causes definite disturbances in growth, as well as in the vigour and health of the studied trees.
3. The increased content of chlorine in the leaves was accompanied by a significant lowering of the content of magnesium and, to a lesser degree, calcium. It did not, however, influence the contents of nitrogen, potassium, sulphur, and phosphorus.
4. A good indicator of the state of health of street-side trees seems to be the ratio of the sum of organic acids ($R\text{-}COO^-$) to the sum of mineral anions ($H_2PO_4^- + SO_4^{2-} + Cl^-$) expressed in chemically equivalent values. A value of this ratio below one clearly indicates poor health and vigour of trees, with the state being more severe when this ratio is clearly lower than one.

References

1. FLÜCKIGER W., BRAUN S. Perspectives of reducing the deleterious effect of de-icing salt upon vegetation. Plant Soil. **62**, (3), 527, **1981**.
2. DMUCHOWSKI W., BADUREK M. Condition of street-side greenery in Warsaw based on many years of observation and experiments by the Botanical Garden – CZRB PAN. Materials from The Science and Technology Conference Warsaw, Greenery Problems and Hopes – 5 Years Later, Warsaw, 4.10.2001: pp. 19-31, **2001** [In Polish].
3. SHORTLE W.C., RICH A.E. Relative sodium tolerance of common roadside trees in southeastern New Hampshire. Plant Dis. Rep. **54**, 360, **1970**.
4. ALAOUI-SOSSE B., SEHMER L., BARNOLA P. DIEZENGREMEL P. Effect of NaCl salinity on growth and mineral partitioning in *Quercus robur* L., arhythmically growing species. Trees. **12**, 424, **1998**.
5. BROGOWSKI Z., CZARNOWSKA K., CHOJNICKI J., PRACZ J., ZAGÓRSKI Z. Salt stress influence on the chemical condition of tree leaves within the city of Łódź. Roczn. Gleboznawcze. **51**, (1-2), 17, **2000** [In Polish].
6. DMUCHOWSKI W., SOŁTYKIEWICZ E., WOŹNIAK J. The effect of urban environment on the phenological development of Tilia 'Euchlora' trees. Monographs of Botanic Garden. pp. 1141-1145, **2007**.
7. OLEKSYN J., KLOEPPEL, B.D., LUKASIEWICZ S., KAROLEWSKI P., REICH P.B. Ecophysiology of horse-chestnut (*Aesculus hippocastanum* L.) in degraded and restored urban site. Pol. J. Ecol. **55**, (2), 245, **2007**.
8. CEKSTERE G., NIKODEMUS O., OSVALDE A. Toxic impact of the de-icing material to street greenery in Riga, Latria. Urban Forestry & Urban Greening. **7**, (3), 207, **2008**.
9. LUNDMARK A., JANSSON P.E. 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, **2008**.
10. POLANCO M.C., ZWIĄZEK J.J., VOICU M.C. Responses of ectomycorrhizal American elm (*Ulmus americana*) seedlings to salinity and soil compaction. Plant Soi., **308**, (1-2), 189, **2008**.
11. MUNCK I.A., NOWAK R.S., CAMILLI K., BENNETT C. Long-term impacts of de-icing salts on roadside trees in the Lake Tahoe Basin. Phytopathology. **99**, (6), S91, **2009**.
12. SHIMOSE N. Salt tolerance of crops. JARQ. **7**, (3), 178, **1973**.
13. BROGOWSKI Z., CZERWIŃSKI Z., PRACZ J. The influence of NaCl salt on the ionic balance of certain park trees. Roczn. Nauk Roln. **102**, (2), 51, **1977** [In Polish].
14. ZOLG M., BORNKAMM R. On the effects of de-icing salt on some chemical constituents of leaves of different road-side trees. Flora. **174**, 285, **1983** [In German].
15. BOGEMANS J., NEIRINCKX L., STASSART J.M. Effect of deicing chloride salts on ion accumulation in spruce (*Picea abies* (L.) sp.). Plant Soil. **113**, 3, **1989**.
16. BOGEMANS J., NEIRINCKX L., STASSART J.M. Effect of deicing NaCl and $CaCl_2$ on spruce (*Picea abies* (L.) sp.). Plant Soil. **120**, 203, **1989**.
17. CHMIELEWSKI W., DMUCHOWSKI W., SUPŁAT S. Impact of Urban Environmental Pollution on Growth, Leaf Damage and Chemical Constituents of Warszawa Urban Trees. Proceedings of the International Symposium on Air Pollution and Climate Change Affects on Forest Ecosystems, Riverside, USA, February 5-9, 1996, USDA Forest Service, General Technical Report, PSW-GTR-166, 1999, pp. 215-220, **1999**.
18. LOUPASSAKI M. H., CHARTZOULAKIS K. S., DIGALAKI N. B., ANDROULAKIS I. I. Effects of salt stress on concentration of nitrogen, phosphorus, potassium, calcium, magnesium, and sodium in leaves, shoots, and roots of six olive cultivars. J. Plant Nutr. **25**, (11), 2457, **2002**.
19. DMUCHOWSKI W., BADUREK M. Chloride and sodium in the leaves of urban trees in Warszawa in connection to their health condition. Ecological Chemistry and Engineering, **11**, (4-5), 297, **2004**.
20. AZZA MAZHER A.M., FATMA EL-QUESNI E.M., FARAHAT M.M. Response of ornamental plants and woody trees to salinity. Word J. Agriec. Sci. **3**, (3), 386, **2007**.
21. GREEN S.M., MACHIN R., CRESSER M.S. Effect of long-term changes in soil chemistry induced by Road salt applications on N-transformations in roadside soils. Environ. Pollut. **152**, 20, **2008**.
22. ALLEN S. E., GRIMSHAW H. N., PARKINSON J. A., QUARMBY C. Chemical Analysis of Ecological Materials. Blackwell Scientific Publications, Oxford, **1974**.
23. PERKIN ELMER. Analytical methods for atomic absorption spectrophotometry. Bodenseewerk, Pub. **B353**, pp. 233, **1990**.
24. MORTON S., ROBERTS D. 1. ATI unicam, atomic absorption spectrometry – methods manual. Issue 2, Unicam LTD, pp. 398. **1991**.

25. LACROIX R. L., KEENEY D. R., WALSH L. M. Potentiometric titration of chloride in plant tissue extracts using the chloride ion electrode. Soil Science And Plant Analysis, **1**, (1), 1, **1970**.
26. LECO CORPORATION. Application Bulletin. St. Joseph, Mi, **1987**.
27. VAN TUIL H.D., LAMPE J.E.M., The possibility of relationship ash alkalinity to the organic salt content. Jaarbook J.B.S. pp. 157-160. **1964**.
28. DE WIT C.T., DIJKSHOORN W., NOGGLE J.C. Ionic balance and growth of plants. Versl. Landbouwkunde Onderzuk. Wageningen **69**, 66, **1963**.
29. KAYAMA M., QUERESHI A.M., KITAOKA S., KITAHASHI Y., SAKAMOTO Y., MARUYAMA Y., KITAO M., KOIKE T. Effects of deicing salt on the vitality and health of two spruce species, *Picea abies* Karst., and *Picea glehnii* Masters planted along roadside in northern Japan. Env. Pollut. **124**, 127, **2003**.
30. CZERNIAWSKA-KUSZA I., KUSZA G., MARIUSZ DUŻYŃSKI M., Effect of deicing salts on urban soils and health status of roadside trees in the Opole region. Environ. Toxicol. **19**, (4), 296, **2004**.
31. BACH A., PAWŁOWSKA B. Effect of sodium chloride salinity and pH of soil on ornamental urban trees in Kraków with regard to nature conservation in cities. Ecological Chemistry and Engineering. **13**, (6), 455, **2006**.
32. OLEKSYN J., KLOEPPEL B.D., ŁUKASIEWICZ S., KAROLEWSKI P., REICH P.B. Ecophysiology of horse chestnut (*Aesculus hippocastanum* L.) in degraded and restored urban sites. Pol. J. Ecol. **55**, (2), 245, **2007**.
33. SHORTLE W.C., RICH A.E. Relative sodium tolerance of common roadside trees in southeastern New Hampshire. Plant Dis. Rep. **54**, 360, **1970**.
34. CZERWIŃSKI Z. The influence of chemical technologies used in street snow removal on soils and tree vegetation of urban agglomerations. Zeszyty naukowe SGGW-AR w Warszawie, Rozprawy naukowe, **104**, 1, **1978** [In Polish].
35. PRACZ J. The influence of chemical technologies used in street snow removal on soils and tree vegetation of urban agglomerations. Phd dissertations, The Institute of Soil Science, SGGW-AR, Warszawa, (Manuscript) **1978** [In Polish].
36. TRILLMICH H.D. Nutrition and fertilization of coniferous plant in Hügelland. Tagungsberigcht der Deutschen Akademie der Landwirtschaftswissenschaften zu Berlin, **112**, 153, **1970** [In German].
37. SMIDT S. Damaging and nutritious substances in plant leaves – contents natural and boundary values. Interner Bericht. **3**, 1, **1988** [In German].
38. BERGMAN W. Colorful atlas of damage related with nutrition at plants. VEB Gustav Fischer Verlag, Jena, **1983** [In German].
39. SCHABERG P.G., TILLEY J.W., HAWLEY G.J., DeHAYES D.H., BAILEY S.W. Associations of calcium and aluminium with the growth and health of sugar maple trees in Vermont. For. Ecol. and Management. **223**, 159, **2006**.
40. BERNIER B., BRAZEU M. Magnesium deficiency symptoms associated with sugar maple dieback in a Lower Laurentians site in southeastern Quebec. Can. J. For. Res. **18**, (10), 1265, **1988**.
41. BERNIER B., BRAZEU M. Foliar nutrient status in relation to sugar maple dieback and decline in the Quebec Appalachians. Can. J. For. Res. **18**, (6), 754, **1988**.
42. BERNIER B., BRAZEU M. Nutrient deficiency symptoms associated with sugar maple dieback and decline in the Quebec Appalachians. Can. J. For. Res. **18**, (6), 762, **1988**.
43. MATTSON A. Ionic relationship of soil land plant. The differentiated root activity in relation to ionic distribution between roots and tops. Acta Agric. Scand., **25**. 2.2, 126, **1975**.