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Research Araştırma

NUTRIENT ACCUMULATION IN STREET GREENERY OF RIGA (LATVIA) IN INCREASED SALINITY CONDITIONS, 2005 AND 2007

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Abstract: One of the most widespread tree species of street greenery in Central, Northern and Eastern Europe, int. al. in Riga (Latvia) located in the boreo-nemoral zone, is lime tree *Tilia x vulgaris* H. A topical problem in the boreo-nemoral zone is using of de-icing material in winter to prevent ice formation on roads and salt accumulation in greenery. The aim of the research was to find out the macronutrient status in the street greenery of Riga to reveal the effect of de-icing salt accumulation on the element supply and the vitality of *T. x vulgaris*. The concentrations of K, Ca, Mg and Na, Cl^- were estimated in lime leaf and soil samples collected from 27 study sites (5 streets or 8 objects) in Riga from March 2005 to August 2007, but the concentrations of N, P and S in samples from June and August 2007. Additional three sites in a park area were chosen for the background level. A bioindication research on the vitality of the street greenery carried out in August of 2005 and 2007 revealed mainly damaged status of lime trees. The damages to the deciduous trees typically appeared as leaf necrosis and dead branches. Ordination with principal component analysis (PCA) of results showed a high heterogeneity of the soil and lime leaf chemical composition. A negative medium close correlation was found between the concentration of Na and K in the leaf samples in July and August 2005 and August 2007, as well as between Na and Mg in June 2005. Our research did not reveal a statistically significant correlation between the content of Cl^- and its antagonists (N, S, P) concentrations in lime leaf and soil samples, as exception – there was a negative medium close correlation between the Cl^- and Ca in lime leaves of August 2007. The main problems of the mineral nutrition of the street greenery in Riga during 2005 and 2007 were elevated concentration of Ca, Mg and P, decreased concentration of N, S and, especially, K in soil, which could be promoted by Na and Cl^- regular accumulation in soil, as well as other factors. Whereas insufficient amount of K and in several sites S, Mg and P, was stated in lime leaves in 2005 and 2007. Probably, it could be facilitated by Na^+ and Cl^- antagonism in the street greenery of Riga.

Key Words: Elements, De-icing salt, Street trees, Soil, Lime leaves

1. INTRODUCTION

Plant supply with mineral nutrients, which functions can not be replaced by other chemical elements, is an important factor for normal plant growth and development. In the boreo-nemoral zone street trees are subjected by many negative factors, int. al., imbalanced plant supply with nutrients, as well as de-icing salt accumulation in greenery soil. Our previous works on chestnut and lime in Riga (Latvia), located in the boreo-nemoral zone, showed a regular and intensive accumulation of Na^+ and Cl^- in street greenery snow, soil and tree leaves reaching toxic amounts (Cekstere et al., 2008). Both Na^+ and Cl^- have antagonistic effect on plant nutrient uptake (Marschner, 1995; Neuman et al., 1996). An inadequate supply with biogenous elements and regular accumulation of de-icing salts in street greenery is a very serious problem causing disturbances in different plant physiological processes, decreasing tree tolerance to unfavourable factors, therefore influencing greenery ecological functions. According to Mertens et al. (2007) there are differences in nutrient accumulation between plant species growing in the same soils, as well as differences due to regional variations, sampling time, pollution etc. Results of different urban soil studies are also difficult to compare due to differences in soil extraction. One of the most widespread tree species of street greenery in Central, Northern (Sæbø et al., 2003) and Eastern Europe, int. al., Riga (Latvia) is lime tree - *Tilia x vulgaris* H. Thereby, nutrient supply for *T. x vulgaris* in the street greenery based on soil and plant chemical analysis in conditions of increased salinity has not been investigated sufficiently. The object of the research was to find out the macronutrient status in the street greenery of Riga to reveal the effect of de-icing salts on the element supply and the vitality of street trees *T. x vulgaris*.

2. MATERIAL AND METHODS

The study was conducted in Riga (a capital of Latvia, Eastern Europe) - situated along the Baltic Sea at the southern part of the Gulf of Riga in the boreo-nemoral zone. The climate of Riga is moderately warm and humid. The mean annual amount of precipitation is 700-720 mm. The average temperature in January is - 4.7°C, in July - +16.9°C (Anonymous, 2005). 27 old street trees (8 objects, to ~100-year-old trees) and 3 trees growing in a park (one object - a background level) were selected in the central part of Riga in 2005 (Figure 1), but in 2007 – 26 street trees as one tree was decayed. Each object consisted of 3-4 neighbouring trees located up to 3 m from the edge of the road with intensive traffic.

Soil samples (obtained from three sub-samples) were collected from a tree-rooting zone (roadside) to a depth of 35 cm in March, June and July 2005, June and August 2007. For each plant sample 50 leaves (just reaching maturity and full size) were collected from different branches of trees along roadsides during the vegetation season of 2005 (June, July and August) and 2007 (June and August).

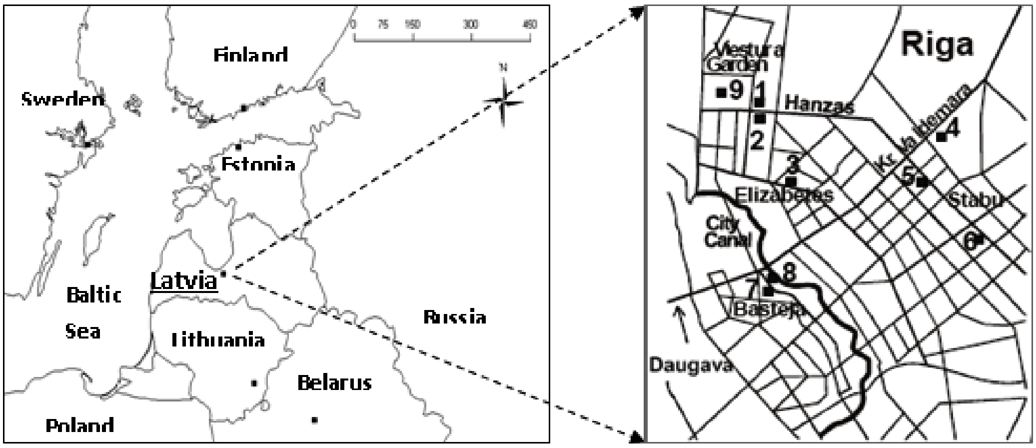

Figure 1. Studied object location in the central part of Riga. (1 – Hanzas 1; 2 – Hanzas 2; 3 – Elizabetes; 4 – Kr. Valdemara; 5 – Stabu 1; 6 – Stabu 2; 7 – Basteja 1; 8 – Basteja 2; 9 – Viestura Garden (park/background level)

After tree crown pruning in winter 2005 leaf sampling was not possible for 6 trees (2 objects) in June 2005. Along with leaf sampling in August an assessment of the physiological status of the street trees (healthy, slightly damaged, medium damaged and severely damaged) was done.

The soil samples were dried at +35°C and sieved <2 mm. To determine the plant available amounts of 6 macronutrients and Na the soil samples were extracted with 1 M HCl solution. The leaf samples were washed with distilled water, dried at +60 °C, ground, then dry-ashed in concentrated HNO_3 vapour, re-dissolved in HCl solution. Ca and Mg were determined by AAS (*Perkin Elmer AAnalyst 700*); K, Na - by flame photometer (*JENWAY PFPJ*); N, P - by colorimetry, S - by turbidimetry, Cl^- - by $AgNO_3$ titration in all samples of 2007 (Rinkis et al., 1987). The level of K, Ca, Mg, Na and Cl^- was estimated in samples collected in 2005.

Statistical analyses of chemical results were done using *SPSS 14.0 version*. The correlation coefficients were classified as follows: r<0.5 week, 0.5<r<0.8 medium close, and r>0.8 close correlation, p<0.05. Ordinations with principal component analysis of results were done using *PC-ord5*.

3. RESULTS AND DISCUSSION

The results of the street tree's vitality in Riga (Table 1) revealed mainly seriously damaged status for *Tilia x vulgaris* during the vegetation season of 2005 and 2007 (in 2005: 17.81 % healthy, 7.41 % slightly damaged, 22.22 % medium damaged, 55.56 % severely damaged trees; in 2007: 15.38 % healthy, 3.85 % slightly damaged, 34.62 % medium damaged and 46.15 % severely damaged trees). The main typical damages for trees were: leaf necrosis, crown defoliation and dead branches, as well as insect damages.

Vast ranges of optimal and average concentrations of nutrients have been found in different studies on *Tilia* spp. (Insley et al. 1981; Bergmann 1988; Kopinga, van den Burg 1995; Nollendorfs 2003; Čekstere et al. 2005). Our soil and lime leaf chemical results also revealed a high heterogeneity of macronutrient, as well as Na and Cl^- concentrations in the street greenery (Figures 2 & 3). The lowest element concentration variance in soil and leaf samples was stated for nonmetals S and N, but the highest variance for metals Ca and Mg. There was no close correlation between the concentration of macronutrients, as well as Na and Cl^- in the soil and lime leaves.

The use of de-icing salt (NaCl) caused a considerably increased Na and Cl^- accumulation in the street greenery soil, especially at the end of winter 2005, and lime tree leaves to compare with the park (Figures 2 & 3). In several sites the concentration of Na in soil samples of March 2005 was even more than 1000 mg/kg (max. 1568 mg/kg), which exceeded the background values by up to 51 times. The decrease in Na and Cl^- concentrations from March to July of 2005, as well as from June to August of 2007 was likely due to leaching from upper layer of the soil, percolation deeper into soil and uptake by plants. However the concentrations of Na, unlike Cl^-, in the soil of the street greenery remain still increased during the both vegetation periods. Our results revealed that the concentrations of Cl^- in the street soil samples collected in June 2005 and 2007 on average were not significantly different, while results of Na were significant higher in 2005 to compare with 2007. Such situation could be explained by the winter season of 2006/2007, which was warmer in comparison to 2004/2005 (www.meteo.lv/public). As a result, decreased amounts of de-icing salts were applied on streets and decreased accumulation of ions occurred in the street soil. Besides, Cl^- as anions are more leachable from the soil and more rapid decrease in concentrations to compare with Na^+ occurred. Cl^- usually follow the water and do not take part in chemical reactions, while Na^+ participate in chemical processes in the soil and are to a great extent retained in the upper part of the soil profile (Lundmark, Olofsson, 2007).

Table 1. Description of studied objects in Riga

Object	Distance of tree's stems to street	Status of trees in August 2005 and 2007
1: Hanzas 1 (3 trees)	~2m	2005: severely damaged (*); 2007: severely damaged.
2: Hanzas 2 (3 trees)	~2.15m	2005: medium damaged: 2007: medium damaged.
3: Elizabetes (5 trees)	~0.7m	2005: 1-healthy, 1-slightly damaged, 3- severely damaged; 2007: 1-healthy, 3-severely damaged, 1-dead in 2006.
4: Kr.Valdemara (3 trees)	~0.7m	2005: 1-medium damaged, 2-severely damaged; 2007: medium damaged.
5: Stabu 1 (3 trees)	~0.6m	2005, 2007: 2-medium damaged, 1-severely damaged.
6: Stabu 2 (4 trees)	~0.6m	2005: 1-slightly damaged, 3-severely damaged; 2007: 1-slightly damaged, 1-medium damaged, 2-severely damaged.
7: Basteja 1 (3 trees)	~3.5m	2005, 2007: healthy.
8: Basteja 2 (3 trees)	1.0-1.5m	2005, 2007: severely damaged.
9: Park (3 trees)	>50m	2005, 2007: healthy.

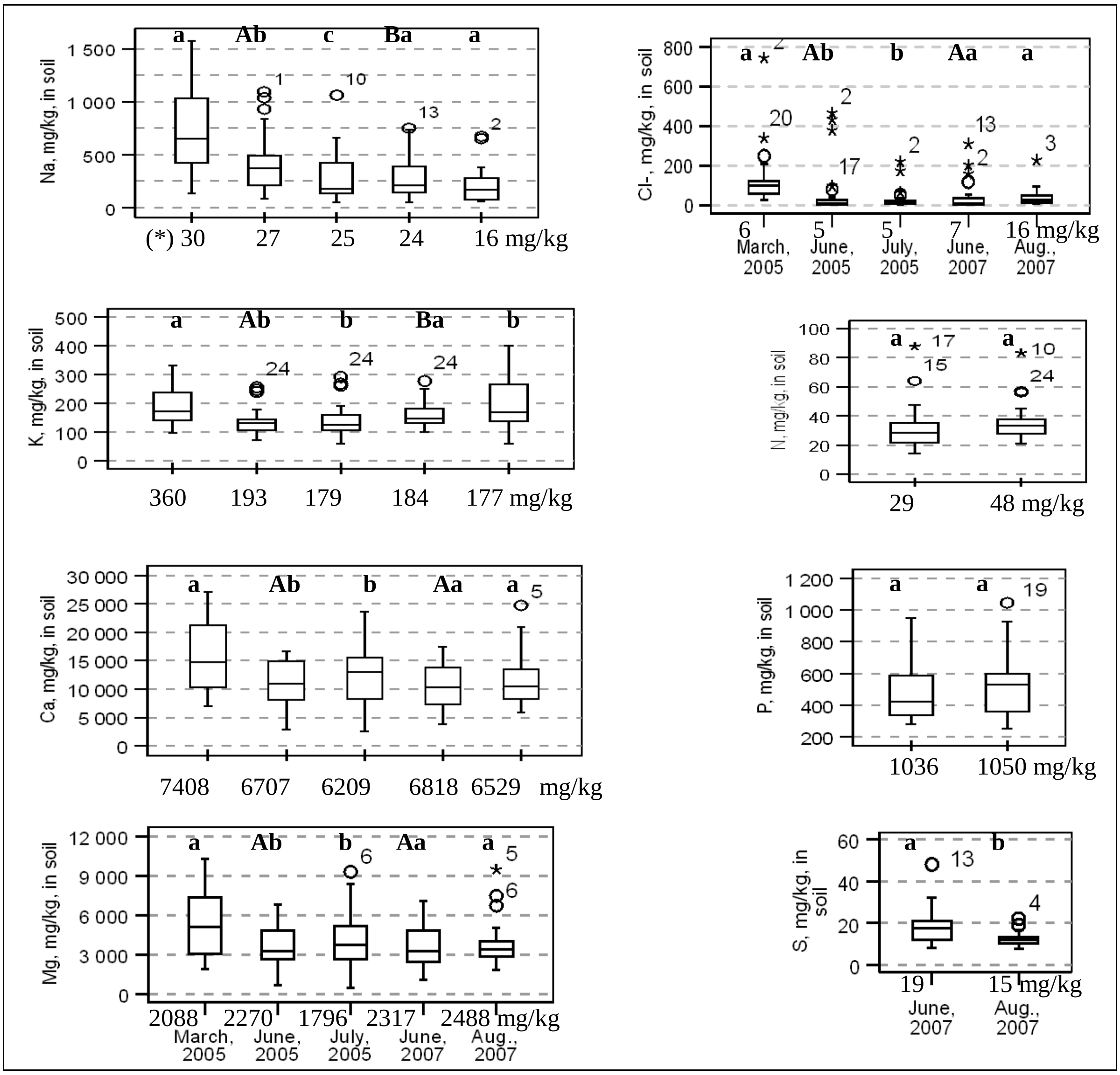

Figure 2. Macronutrient, Na and Cl^- concentration in soil samples in Riga during 2005 and 2007 (* - background level (park) abc – to compare the results between the months during one year AB – to compare the results between the same months of different years)

The analysis of plant material showed that the soil salinity induced increased Na and Cl^- concentrations in lime leaves in sites with higher soil salinity during 2005 and 2007. During the vegetation seasons, Na ranged from 0.01 % in June to 1.93 % in August, which was up to 48 times higher than at the park, but Cl^- concentration ranged from 0.17 % to 3,00 %, and was more than 25 times above the background level. The lowest concentrations of Na and Cl^- in lime leaves were found in sites situated about 3.5 m from the carriageway. These limes were characterized as healthy. In general, the concentrations of Na and Cl^- in tree leaves showed a tendency to increase during the vegetation periods, except Cl^- in summer of 2007. The investigation revealed a significant problem in the street tree supply with K, which is one of the main antagonistic elements to Na (Figure 2). A low level of K was stated for most of the street soil sites at the beginning of spring 2005 (96-200 mg/kg), which continued decreased markedly during the vegetation season (up to 61 mg/kg). Also the concentrations of K in the soil from the vast majority of sampling sites (2005) were lower to compare with the park. It was consistent with other studies in urban areas where soil contented construction and demolition wastes (Meyer, 1978; Čekstere et al., 2005).

The results showed a negative medium close correlation between the level of K in the soil samples of March 2005 and Na in the leaves during summer 2005 (r_{June}=-0.65, n=21, r_{July}=-0.61, $r_{Aug.}$=-0.58, n=27) revealing the great importance of soil chemical composition in early spring. To compare two-year results, the level of K in the street soil samples was statistically significant higher in June 2007, contrary to Na. In most of the studied street sites the level of K in the soil was the same as in the park or even elevated, and showed a tendency to increase from June to August, probably due to application of K containing fertilizers. Less amounts of Na in the street soil, which could displace K in the exchange sites in the soil, resulted in improved the K/Na ratio in 2007. In total, the K/Na ratio in the soil samples from the park ranged from 4.15 to 13.48. In the street soils, for healthy limes, the K/Na ratio was 0.13-6.45, for medium damaged limes - up to 4.82, and for damaged trees - 0.07-2.66. It means that the narrow K/Na ratio in the street soil samples had additive harmful impact on the tree status. Better street trees supply with K and lower Na amounts in soil, resulted in higher concentrations of K in lime leaves collected in 2007 to compare with results of 2005. The smallest K result (0.15%) stated in 2005 was even up to 6.33 times lower to compare with the min. K concentration in lime leaves in the park. The status of tree – damaged. At the same time the highest concentrations of K (max. 3.40%) were also stated in lime leaves with necrosis, which mean that sufficient supply with K could not prevent the appearance of leaf necrosis. In Riga, K concentration in healthy lime leaves without necrosis ranged from 0.76% to 2.42%, which was in good agreement with results generalized by Polevoi (1989). The reduction of K in lime leaves during the summer could be explained by reutilization in plant and antagonistic effect of Na ($r_{Na,K\ Aug.2005}$= -0.68, n=27; $r_{Na,K\ Aug.2007}$= -0.44, n=26).

As the external salt concentration rises, the concentration of Na^+ increases and that of K^+ decreases in the roots and leaves. It appears that Na^+ out-compete K^+ for specific binding sites on the K^+ transport proteins, causing K^+ deficiency (Denny 2002; Subbarao et al. 2003). As the result, the decrease of K/Na ratio from June to August was stated. The K/Na ratio for healthy lime leaves without necrosis in Riga's street greenery ranged from 2.92 to 237 (in park: 24.12-270.83), but for leaves with severe necrosis (>30 %) ranged even from 0.15 to 72.00. In general, the stated K/Na ratio diapasons in Riga were substantially wider to compare with results reported by Czerniawska-Kusza et al. (2004) in Opola for *Tilia cordata* (1.76-15.65). It can be concluded that sufficient K/Na ratio in lime leaves did not have determinant role, if the stated leaf necrosis were caused by Cl^- toxicity, or the Na concentration in leaves reached toxic level.

In general, lime tree supply with P in 2007 and Ca, Mg during the vegetation season of 2005 and 2007 in soil could be characterized as optimal to excessive. Soils of Riga are highly anthropogenic, containing in different amounts brick peaces, building remains, as well as constructional dust etc., which contain Ca and Mg. Accordingly, optimal till abundant levels of the elements were stated in the leaves. Expressed tendency for Ca in lime leaves was stated: concentration of Ca increased during the both vegetation periods, as Ca in plants formed insoluble compounds and was not subjected for reutilization. However, the found Mg content in lime leaves less than 0.20% in some streets, probably, due to element antagonism and hard soluble compounds could be insufficient for normal plant development. Na^+ in soil can replace not only K^+, but also Ca^{++}, Mg^{++}, NH_4^+ and other cations on the soil exchange complex. This could lead to nutrient deficiencies and caused injury (Marschner 1995; Sieghardt et al. 2005). A negative, medium close correlation was found between the elevated concentration of Na in the lime leaves and Ca, Mg content in the leaves, especially for June 2005 ($r_{Na,Ca}$=-0.46, $r_{Na,Mg}$=-0.54, n=21). The results of P concentrations in the street greenery soil are consistent with the studies of Ripa and Petersons (1968) on greenery soils in Riga, where high or toxic levels of P were stated, but differ from those of Meyer (1978), who found decreased levels of P and K in substrates with increased contents of artificial materials with alkaline reaction. This fact in Riga could be explained by possible application of phosphate fertilizers, as well as formation of hard soluble P compounds in the neutral and alkaline greenery soils (Cekstere, Osvalde, 2009).

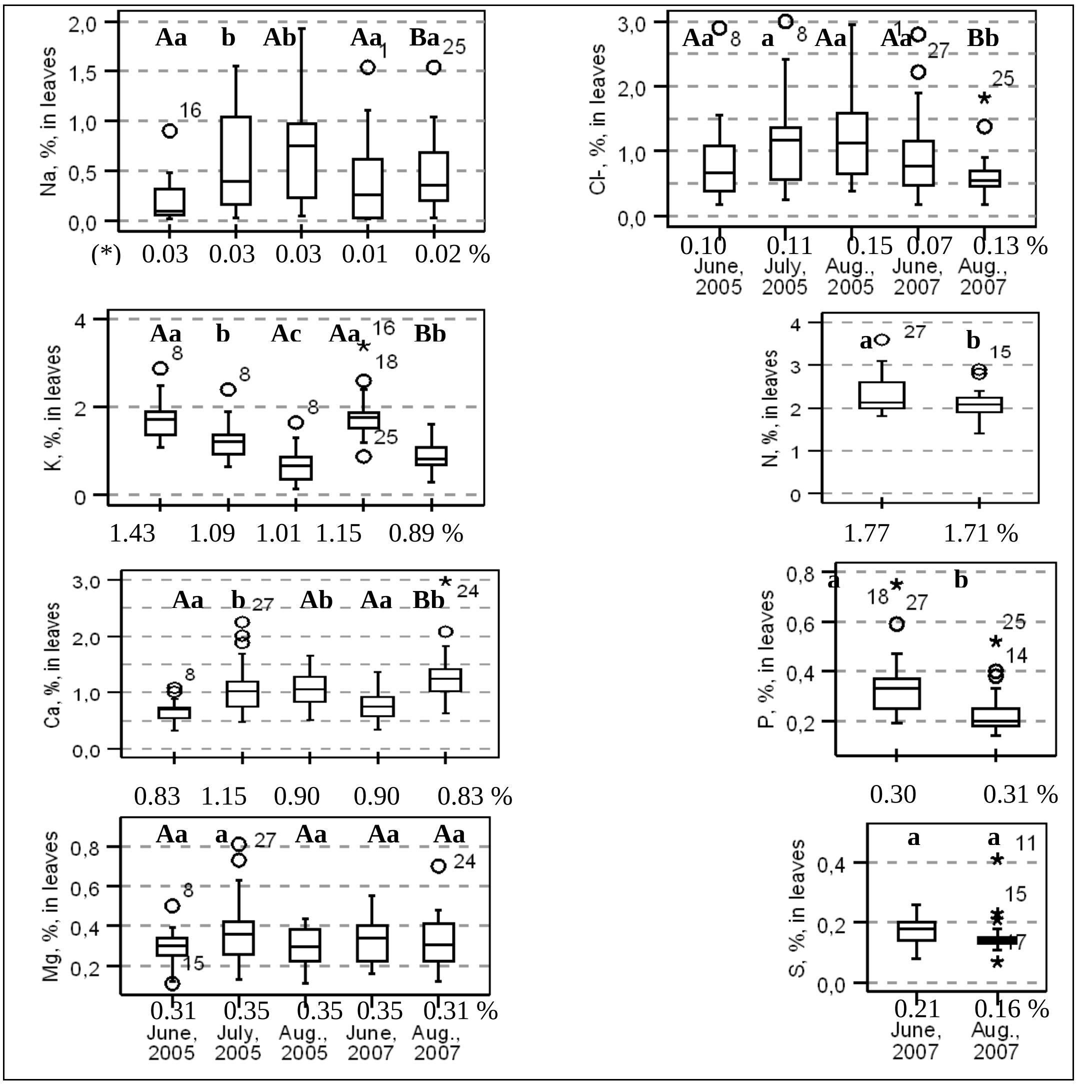

Figure 3. Macronutrient, Na and Cl^- concentration in lime leaf samples in Riga during 2005 and 2007(*) - background level (park) abc – to compare the results between the months during one year. AB – to compare the results between the same months of different years

Thus the stated P concentrations in leaves, mainly in August of 2007, showed insufficient to optimal levels. Our study revealed low levels of N and S in the vast majority of the analyzed soils in June and August of 2007. These results were in a good agreement with other studies in urban areas (Oleksyn et al. 2007).S and N as anions are more leachable from soil to compare with cations. Low levels of S and N in soils of street trees could be due denitrification and desultification processes as the street soils in Riga are highly compact. In highly industrialized areas S requirement of plants is often met to a substantial degree by atmospheric SO_2 pollution. During the last decades industrial SO_2 emissions have been drastically decreased in Western and Northern Europe, int. al. in Latvia and Riga (Jankovska et al. 2008). As the result the low levels of S and N in the soils did not correspond to the optimal demands of plants. Accordingly decreased concentrations of S (in several sites below 0.12 %) were also stated in the lime leaves. Different studies have showed that NaCl is a decisive factor that may be responsible for the decreased level of foliar N via a reduction in NO_3^-, NH_4^+ uptake (Neuman et al. 1996; Oleksyn et al. 2007). In general, almost sufficient level of N in lime leaves (June: 2.34±0.09 %; August: 2.09±0.06 %) could be explained by NO_x uptake from air due to increased air pollution with NO_x during the last decades in Riga (Ļuļko et al. 2008). It is well known that plants can uptake NO_2 through leaf stomata (Manning and Harris 2009). However, the reduction of N and P concentration in the lime leaves during the vegetation season is in a good agreement with other studies on N and P seasonal changes (Chapin, Kedrowski, 1983). In total, our research did not reveal statistically significant correlation between the content of Cl^- and its antagonist (N, S, and P) concentration in lime leaf and soil samples. Exception – there was a negative correlation between the Cl^- and Ca in lime leaves of August 2007 (r=-0.50, n=26). The results of this study confirmed and expanded the data reached in the previous studies on the nutritional status of street trees in Riga. It was found that one of the main negative factors affecting the growth and development of old street trees (limes and chestnuts) was deficiency of N, K and S (Čekstere et al. 2005). Principal component analysis (PCA) of soil results of August 2007 showed 37.44 % variance with Axis 1 and 22.33 % with Axis 2, but PCA of leaf results: 35.27 % and 19.60 % variance, respectively. The spatial distribution of the studied trees according to leaf results showed continuum, but soil results could be characterized as rather structured depending on the street (Figure 4). PCA results of August 2007 revealed some tendencies for the street greenery in Riga: 1) a wide dispersion of the soil and leaf sample chemical composition even in one street; 2) better vitality for trees with lower Na and Cl^- concentration in the soil and leaves, but higher level of Ca, Mg, K and S in the lime leaves; 3) similar chemical composition of detected macronutrients and Na, Cl^- in the soil samples for trees with different level of damages.

4. CONCLUSION

The study revealed a high heterogeneity of macronutrient concentrations in the soil and leaves of the street trees, and mainly medium and severely damaged status for the lime trees in August 2005 and 2007. The main problems of mineral nutrition of the street greenery in Riga during 2005 and 2007 were elevated concentration of P, Ca, Mg and decreased levels of N, S, K, which, probably, could be promoted by Na and Cl^- accumulation in soil. The concentration of K in lime leaves in the most of cases was in insufficient levels and occasionally deficiencies of S, Mg and P was also found. Probably, it could be facilitated by Na^+ and Cl^- antagonistic impact on nutrient uptake in the street greenery of Riga. Our results also suggest that there was no significant improvement during the last five years in the street tree nutritional status.

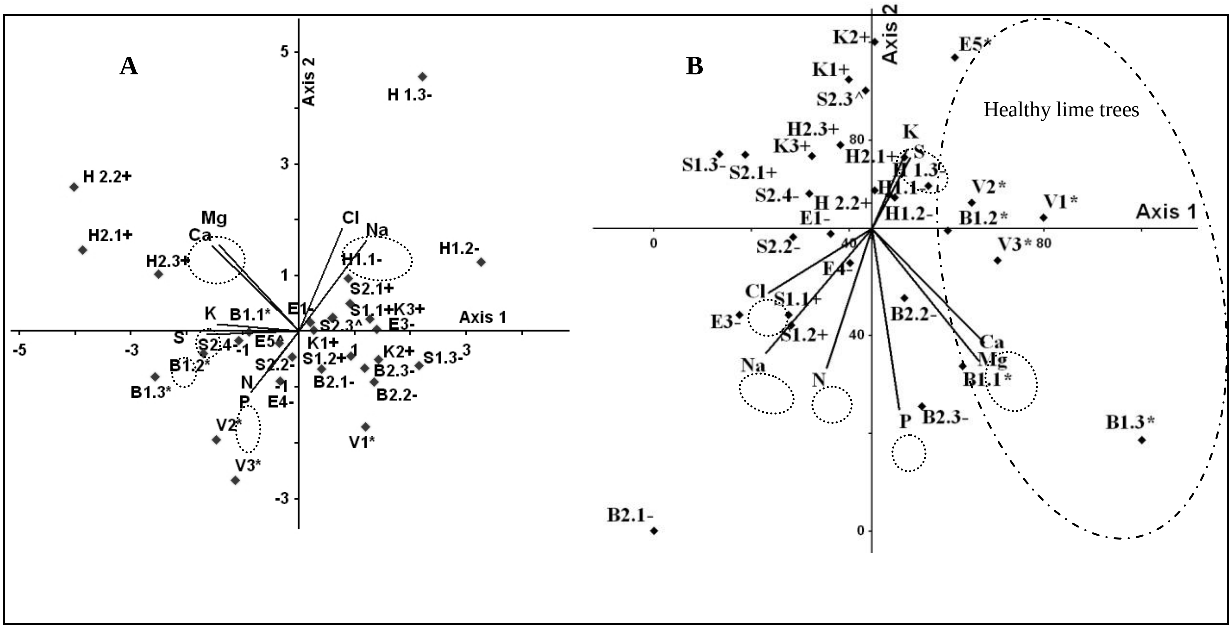

Figure 4. Principal component analysis of soil (A) and lime leaf (B) sample chemical results in Riga, August 2007 (S – the first letter indicates the street; 1 – tree number in the street; * - healthy; ^ - slightly damaged; + - medium damaged; - – severely damaged)

5. ACKNOWLEDGMENT

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