Macronutrient Status in the Different-Aged Lime Trees (*Tilia* x *vulgaris* H.) in Riga Streets

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Abstract

The research was done to evaluate the different-aged Lime trees (*Tilia* x *vulgaris* H.) supply with macronutrients on Riga streets (Latvia). The concentrations of 6 macronutrients (N, P, K, Ca, Mg and S) were estimated in the Lime leaf and soil samples collected from 15 objects (47 individual trees) in Riga during August of 2007. Along with the chemical analysis, a bioindication research was done to diagnose the physiological status of trees. The results revealed that the status of young street trees could be characterized as slightly damaged and damaged for old trees, in general. There was no close correlation between the concentration of element in the soil and lime leaves. Both in the soil and leaf samples the highest element concentration variance was stated for metals Ca and Mg, but the lowest – for nonmetals S and N. Statistically significant differences were found for N, Mg, S in soil samples, and K, P, and S in leaf samples between the young and old lime trees (plantings as greenery). The main factors affecting negative *T.* x *vulgaris* mineral nutrition were very low supply with N, S, K, and elevate concentrations of P, Ca, Mg. Low concentrations of S, K, as well as Mg, P were stated in leaves. Well visible K deficiency symptoms in young tree leaves were observed.

Key words: lime trees, macronutrient imbalance, leaf analysis, soil analysis

Introduction

Trees have many functions and positive effect on surrounding environment not only in forest, but also in urban area (Novak et al. 2006). Unfortunately, street trees commonly are subjected by many negative factors, such as application of de-icing materials on roads during winter, soil and air pollution, as well as inadequate supply with biogenous elements etc. (Craul 1992; Pauleit et al. 2002; Sæbø et al. 2003). One of the most widespread tree species of street greenery in Central, Northern (Sæbø et al. 2003) and Eastern Europe (Sander et al. 2003), int. al., Riga (Latvia) is lime tree *Tilia* x *vulgaris* H., known also as *T.* x *europea* L., *T. intermedia* DC., *T.* x *hollandica* K. Koch. (Bengtsson 2005). Investigations have shown a vast range of optimal and average concentrations of nutrients in *Tilia* spp. (Bergmann 1988, Kopinga and van den Burg 1995, Insley et al. 1981, Nollendorfs 2003, Čekstere et al. 2005). According to Hagen-Thorn (2004) and 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. Thereby, nutrient supply for the young and old *T.* x *vulgaris* in the street greenery based on soil and plant chemical analysis has not been investigated sufficiently. Our previous work on chestnut and lime in Riga showed a severe imbalance in the mineral nutrition of old urban trees (Čekstere et al. 2005) and toxic effect of NaCl (Čekstere et al. 2007, Cekstere et al. 2008). It is a topical issue as street greenery is a relevant element of urban environment and an inadequate supply with biogenous elements can cause disturbances in different plant physiological processes, decreases tree tolerance to unfavourable factors, therefore influences greenery environmental functions. The aim of this investigation was to compare the macronutrient status in the different-aged trees on Riga streets and reveal the effect of element supply on the vitality of street trees *T.* x *vulgaris*.

Materials and methods

Study area. The study was conducted in Riga, which is situated along the Baltic Sea at the southern part of the Gulf of Riga in the boreo-nemoral zone. The climate of the city is moderately warm and humid. The mean annual amount of precipitation is 700-720 mm. Winters are relatively warm with frequent thaws, the average temperature in January is - 4.7°C. Summers are relatively cloudy and cool. The average temperature in July is +16.9°C. (Anonymous 2005). The central part of Riga with high building density and canyon streets has high level of air pollution - currently are exceeded air quality limit values and target values for NO_2 and PM10 due to intensive traffic (Kleperis 2007, Kleperis 2008). In Riga, parks, gardens, squares and other greenery form 8% of the centre of city (Nikodemus et al. 2003).

Sampling. Soil and leaf samples were collected from 21 young street trees (7 objects, to ~15-year-old trees) and 26-year-old street trees (8 objects, to ~100-year-old trees) with different physiological status in Riga's centre at the end of August 2007 (Fig. 1). 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. For each plant sample 50 leaves (just reaching maturity and full size) were collected from 5-7 different branches of trees along roadsides. Along with leaf sampling an assessment of the physiological status of the street trees was done (Table 1) based on the intensity of leaf damages and crown defoliation (UN/ECE 1994). Samples of wood were collected with a Presler drill at 1.3 m high and tree rings were counted for each tree using a special apparatus LINTAB 4 and a computer program TSAP-WIN to determine their age.

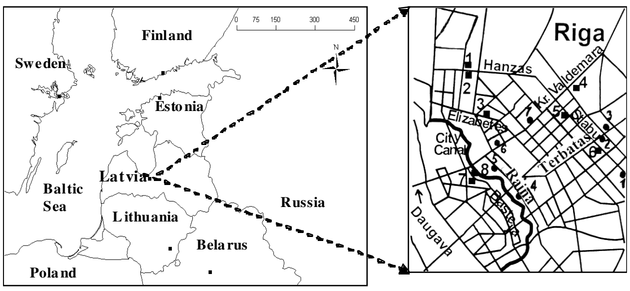

Figure 1. Studied object location in the central part of Riga. (● young street trees: 1 – Stabu; 2 – Terbatas 1; 3 – Terbatas 2; 4 – Raina 1; 5 – Raina 2; 6 – Kr. Valdemara 1; 7 – Kr. Valdemara 2; ■ old street trees: 1 – Hanzas 1; 2 – Hanzas 2; 3 – Elizabetes; 4 – Kr. Valdemara; 5 – Stabu 1; 6 – Stabu 2; 7 – Basteja 1; 8 – Basteja 2.)

Laboratory analysis. The soil samples were dried at +35°C and sieved < 2 mm. To determine the plant available amounts of 6 macroelements (N, P, K, Ca, Mg, S) the soil samples were extracted with 1 M HCl solution (1:5). Soil reaction was estimated in 1 M KCl (1:2.5). The leaf samples were washed with distilled water, dried at +60°C, ground, then dry-ashed in concentrated HNO_3 vapor, re-dissolved in HCl solution (HCl – distilled water mixture 3:100). The levels of Ca and Mg were determined by atomic absorption spectrophotometer (Perkin Elmer AAnalyst 700), those of N and P by colorimetry, S by turbidimetry, K by flame photometer (JENWAY PFPJ) in all soil and plant samples, as well as soil pH - potentiometrically by pHmetr Sartorius PB-20 (Ринькис и др. 1987).

Statistical analysis. t-Test "Two-Sample Assuming Unequal Variances" ($p<0.05$) was used to compare the mean element concentrations in the young and old street trees. Correlation coefficients and significance of element concentration variance were found using Excel 2003. Ordination with principal component analysis (PCA, varimax rotated solution) of results was done using PC-ord4.

Results and discussion

A vast range of optimal and average concentrations of nutrients (Table 2) have been found in different studies on *Tilia* spp. (Insley et al. 1981, Bergmann

Table 1. Description of studied objects in Riga

Young street trees		Old street trees	
Object number and street	Status of trees*	Object number and street	Status of trees*
1. Stabu street	2-healthy; 1-medium damaged	1. Hanzas street 1	3-damaged
2. Terbatas street 1	1-slightly damaged; 2-healthy	2. Hanzas street 2	3- medium damaged
3. Terbatas streeet 2	1-healthy; 1- slightly damaged; 1- medium damaged	3. Elizabetes street	3-damaged, 1-healthy
4. Raina blvd. 1	1-healthy; 1- medium damaged; 1-damaged	4. Kr.Valdemara street	3-medium damaged
5. Raina blvd. 2	3- slightly damaged	5. Stabu street 1	2-medium damaged;1-damaged
6. Kr. Valdemara street 1	2– slightly damaged; 1-damaged	6. Stabu street2	1-slightly damaged; 1-medium damaged; 2-damaged
7. Kr. Valdemara street 2	3- slightly damaged	7. Basteja blvd. 1	3-healthy
		8. Basteja blvd. 2	3-damaged

* healthy - no visible leaf necrosis, 0-10 % crown defoliation; slightly damaged - 1-5 % intensity of leaf necrosis, 11-25 % crown defoliation; medium damaged - 6-20 % intensity of leaf necrosis, 26-40 % crown defoliation; damaged - >21 % intensity of leaf necrosis, >41 % crown defoliation.

Table 2. Optimal and average concentrations of macronutrients (%) in *Tilia* spp. leaves

Reference	N	P	K	Ca	Mg	S
Bergmann 1988 - optimal	2.3-2.8	0.15-0.30	1.00-1.50	0.20-1.20	0.15-0.30	-
Kopinga & van den Burg 1995 - optimal	>2.80	>0.20	>1.50	-	>0.28	-
Insley et al. 1981 – average	2.77-3.08	0.21-0.27	1.00-1.21	2.09-3.33	0.31-0.34	-
Nollendorfs 2003; Čekstere et al. 2005 - average	1.76-2.07	0.25-0.34	0.63-1.25	1.33-1.86	0.38-0.46	0.12-0.17

1988, Kopinga and van den Burg 1995, Nollendorfs 2003, Čekstere et al. 2005). Our study revealed mainly slightly damaged physiological status of young trees and damaged status for old limes in Riga during August of 2007 (Table 1). To characterize the street trees supply with macronutrients in Riga, mean element concentrations in each object, as well as average level found in the young and old trees, are given in Figs. 2 and 3. There was no close correlation (p>0.05) between the concentration of element in the soil and lime leaves. The lowest element concentration variance in soil and leaf samples was stated for nonmetals S and N (7.8-53.3 mg/kg S, 21.0-83.0 mg/kg N in soil; 0.05-0.41 % S, 1.40-2.90 % N in leaves), but the highest – for metals

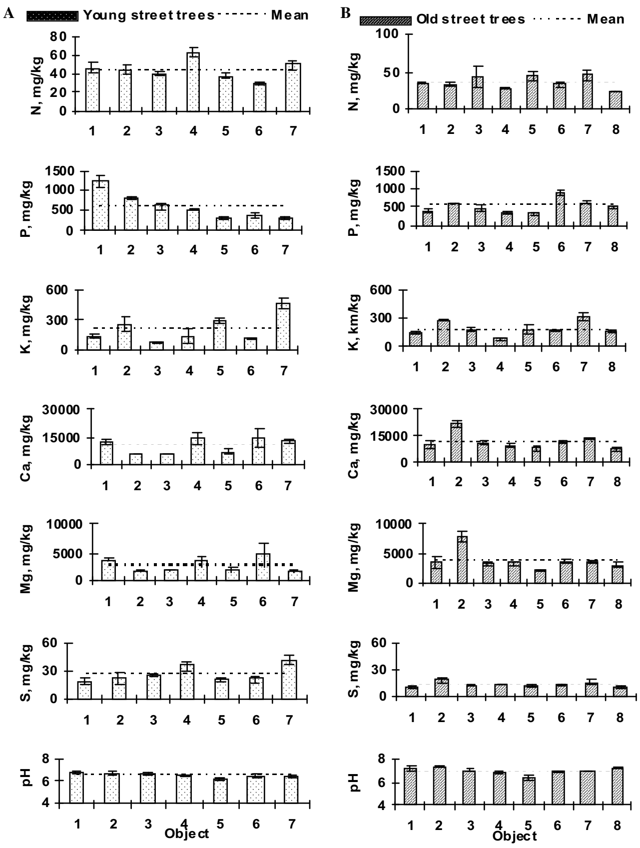

Figure 2. Mean concentration of elements (mg/kg) and pHKCl in soil samples of young (A) and old (B) street trees in Riga during August of 2007. (Young street trees: 1 – Stabu; 2 – Terbatas 1; 3 – Terbatas 2; 4 – Raina 1; 5 – Raina 2; 6 – Kr. Valdemara 1; 7 – Kr. Valdemara 2; old street trees: 1 – Hanzas 1; 2 – Hanzas 2; 3 – Elizabetes; 4 – Kr. Valdemara; 5 – Stabu 1; 6 – Stabu 2; 7 – Basteja 1; 8 – Basteja 2; means from 3-4 samples, ± SE.)

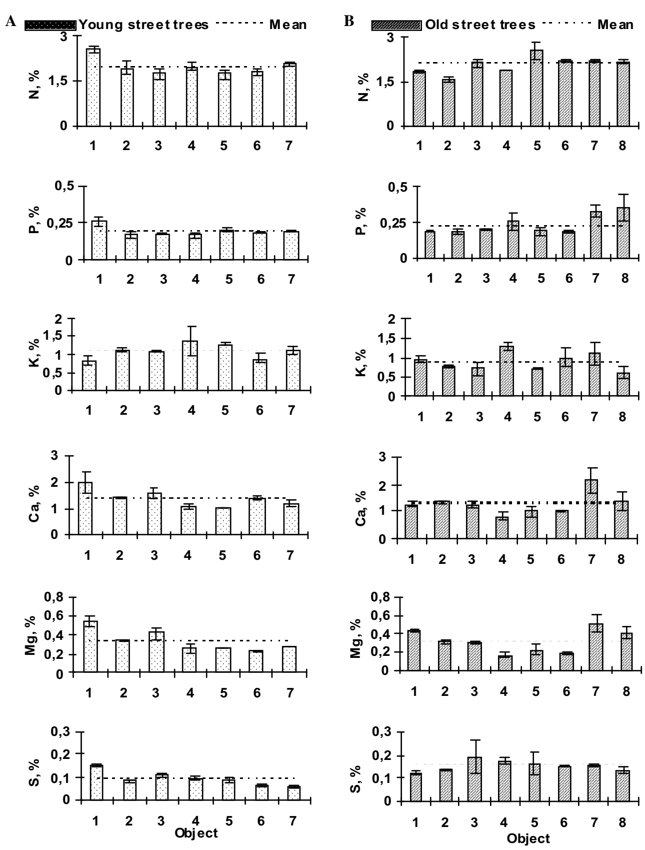

Figure 3. Mean concentration of elements (%) in lime leaf samples of young (A) and old (B) street trees in Riga during August of 2007. Young street trees: 1 – Stabu; 2 – Terbatas 1; 3 – Terbatas 2; 4 – Raina 1; 5 – Raina 2; 6 – Kr. Valdemara 1; 7 – Kr. Valdemara 2; old street trees: 1 – Hanzas 1; 2 – Hanzas 2; 3 – Elizabetes; 4 – Kr. Valdemara; 5 – Stabu 1; 6 – Stabu 2; 7 – Basteja 1; 8 – Basteja 2; means from 3-4 samples, ± SE.)

Ca and Mg (5425-24936 mg/kg Ca, 908-9466 mg/kg Mg in soil; 0.72-2.98% Ca, 0.12-0.70% Mg in leaves).

The research showed low levels of N and S in the vast majority of the analysed soils. S and N as anions are more leachable from soil. 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. Latvia and Riga (Terauda and Nikodemus 2007, Jankovska et al. 2008). As the result the low levels of S and N in the soils did not correspond to the optimal supply of plants, accordingly decreased levels of them were also stated in the leaves, especially for S (in two objects only 0.06±0.01 %). Whereas the soils, where young trees grow in the streets, contain significantly higher levels of S and N as compared with the soils, where old trees grow. Soils of old street trees can be characterized as highly compact, therefore more intense denitrification and desultification could occur and thus fewer amounts of N and S were found in comparison with the young street trees. In addition, application of N and S containing fertilizers in the young greenery, as well as higher organic content (Cekstere, unpublished data) could influence the level of N and S. Interestingly, that the leaf chemical analysis revealed significantly higher level of S in the old lime leaves. Probably, this could be due to dilution effect in the young lime leaves, as well as with S accumulation in the old limes during previous decades, when air pollution with sulphur oxides and acid rains was a serious problem in Riga. In general, almost sufficient level of N in leaves (young trees 1.97±0.07 % ≈ old trees 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). It could be also stressed that soils of street trees in Riga contain relatively high level of organic matter (Cekstere, unpublished data) which were decomposed and formed N compounds available for tree uptake during the vegetation season.

Plant supply with such macroelements as P, Ca, Mg in the soil could be characterized as optimal to increased. Soils of Riga, especially for the old street trees, are highly anthropogenic, containing in different amounts brick peaces, building remains, as well as constructional dust etc., which contain Ca and Mg. Whereas the soils of the young street trees contained significantly lower level of Mg (2629±382 mg/kg < 3749±345 mg/kg, young and old respectively). Accordingly, optimal till abundant levels of the elements were stated in the leaves, which were on average statistically similar between the young and old tree leaves (1.38±0.09 % ≈ 1.27±0.10 % Ca, 0.33±0.03 % ≈ 0.32±0.03 % Mg). Nevertheless, the stated Mg content less than 0.20% in two objects of the old trees (Kr. Valdemara and Stabu 2), probably due to element antagonism and hard soluble compounds, could be insufficient for normal plant development. The results presented here on P in the soils is consistent with the studies of Ripa and Petersons (1968) on soils and trees 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 phenomenon 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. Thus the stated P concentrations in leaves showed decreased to optimal levels. Significantly higher level of P (0.19±0.01 % < 0.23±0.02 %) was found in the old lime leaves due to over an accumulation long time.

In general, the concentrations of K in the soil samples were highly variable (23.4-578.1 mg/kg). Consequently, a wide dispersion of K concentrations and supply levels were stated in lime leaves (K_{max}/K_{min}=6.73). Significantly a higher level of K (1.09±0.07% > 0.88±0.07 %) was found in the young lime leaves. Usually K content in plants decreases during the vegetation season. In Riga it could be promoted by abundance of antagonistic ions, especially Na^+ (Čekstere et al. 2007), as well as insufficient level of K in the soil. As the result the found concentrations of K in lime leaves of Riga could be characterized as insufficient for *Tilia* spp. Well visible K deficiency symptoms as brown necrotic spots were observed (≤0.66 %) only in the young tree leaves. However, such symptoms were not pronounced in the old tree leaves, where the level of K was only 0.30 %. Probably, young trees are more sensitive to K deficiency stress. It could be noted that observation of visual K deficiency symptoms for the old trees were suppressed by intensive specific leaf necroses caused by toxic impact of Na^+ and Cl^- (Čekstere et al. 2007).

The results of this study confirmed and expanded the data obtained in the previous studies on the nutritional status of trees growing in the streets of 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).

PCA of leaf results showed 37.62 % variance with Axis 1 and 21.72 % with Axis 2, but PCA of the soil results: 35.38 % and 27.60 % variance, respectively. The spatial distribution of studied trees according to leaf results showed continuum, but soil results could be characterized as rather structured (Fig. 4). PCA results revealed 4 tendencies for the trees in Riga: 1) tree grouping depending on age (young or old); 2) a wide dispersion of macronutrient concentrations in most of studied objects; 3) better vitality for young trees mainly due to better supply with K; 4) content of macronutrients of the soils and leaves did not reveal significant differences between healthy and damaged trees growing in different streets of Riga, which indicated to other factors (de-icing salts, heavy metals, micronutrients etc.) more negatively affecting physiological status of trees.

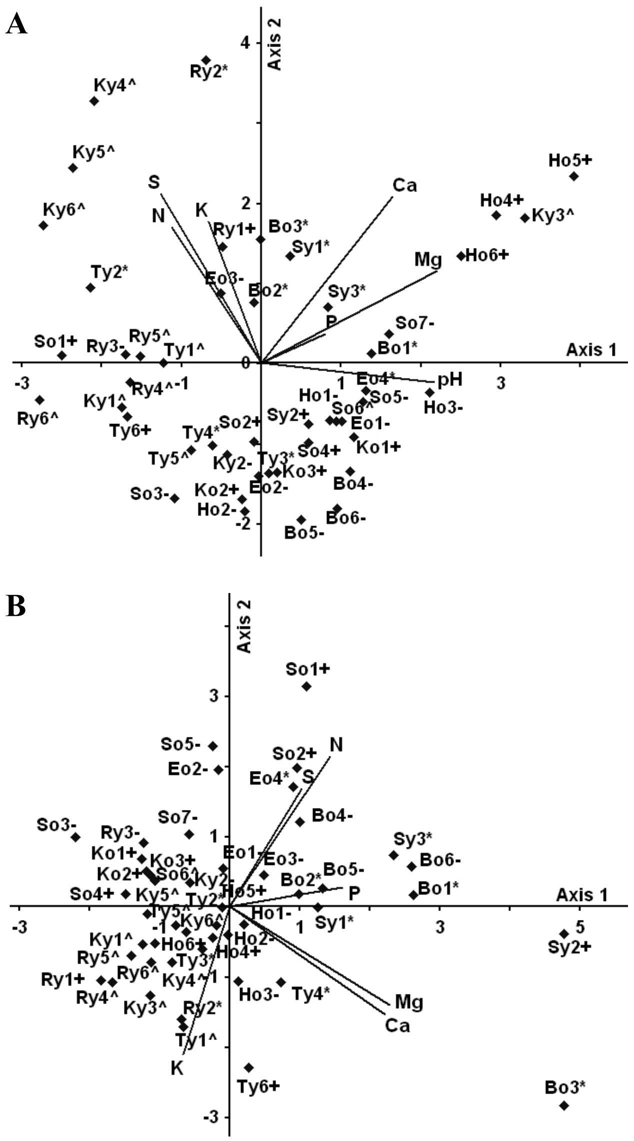

Figure 4. Principal component analysis of soil (**A**) and lime leaf (**B**) sample chemical results in Riga, August 2007. (The first letter indicates the street: S – Stabu, T – Terbatas, R – Raina, K – Kr. Valdemara, H – Hanzas, E – Elizabetes, B - Basteja; y – young tree; o – old tree; 1 – tree number in the street; * - healthy; ^ - slightly damaged; + - medium damaged; - – damaged.)

Conclusions

The research revealed a high heterogeneity of macronutrient concentrations in the soils and leaves of the street trees, slightly damaged status of the young trees and damaged for the old limes in August 2007.

Insufficient level of N, S and K and elevated concentrations of P, Ca and Mg were found in the soils in which young and old trees grow in the streets. The main nutritional problems for the limes in Riga were low foliar level of S and K as well as Mg and P on several sites. Statistically significantly higher concentrations of P and S were found in the old lime tree leaves, but K - in the young tree leaves, however these concentrations of K and S in the most of cases did not reach optimal values.

The results of this study suggest that there is no significant improvement during the last five years in the street tree macronutrient status. Therefore further studies and additional analytical work should be done to work out and evaluate measures and treatments to improve the vitality of trees and ameliorate the unfavourable growth conditions.

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СТЕПЕНЬ ОБЕСПЕЧЕННОСТИ МАКРОЭЛЕМЕНТАМИ РАЗНОВОЗРАСТНЫХ ДЕРЕВЬЕВ ЛИПЫ НА УЛИЦАХ РИГИ

Г. Чекстере и А. Освалде

Резюме

Одной из наиболее распространённых древесных пород в уличных посадках в городах Центральной, Северной и Восточной Европы, в том числе в Риге (Латвия), является липа *Tilia* x *vulgaris* H. Основной целью исследования явилось изучение степени обеспеченности разновозрастных уличных посадок макроэлементами в городе Риге. В августе 2007 года деревья обследовались для диагностики жизнеспособности уличных посадок. На 47 исследуемых площадях были собраны образцы почвы и листьев липы, в которых была определена концентрация N, P, K, Ca, Mg и S. На основании результатов проведенных исследований установлено, что состояние деревьев, в основном, характеризуется как слабо поврежденное для молодых уличных посадок и поврежденное для старых. Наиболее широкий диапазон концентраций, как в образцах почвы, так и в листьях *Tilia* x *vulgaris* был установлен для металлов Ca и Mg, а более узкий – для неметаллов S и N. Статистически достоверные различия между результатами для молодых и старых уличных насаждений были найдены для N, Mg, S в почвах и K, P, S в листьях липы. Выявлено, что главным фактором, отрицательно влияющим на режим минерального питания *Tilia* x *vulgaris*, явилось особенно низкое обеспечение N, S, K, а также повышенные концентрации P, Ca и Mg в почвах. Заниженные концентрации S, K и в отдельных случаях Mg и P были установлены в образцах листьев липы. Ярко выраженные визуальные признаки дефицита K были обнаружены в листьях молодых деревьев *Tilia* x *vulgaris.* При этом прямая зависимость не найдена между содержанием элементов в почве и концентрацией их в листьях липы.

Ключевые слова: липы; дисбаланс макроэлементов; анализ почвы; анализ листьев