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Growth adaptability of Norway maple (*Acer platanoides* L.) to urban environment

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Abstract

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Adaptability of *Acer platanoides* L. to deteriorating urban conditions was assessed through qualitative parameters describing crown destruction, assimilation organs efficiency, chlorophyll *a* content, and content of alochtonous elements in leaves. The adaptability assessment was based on comparison between study trees growing in an environmentally loaded town area and control trees in a historical rural park, both localities in Slovakia (Central Europe). The results of visual assessments performed in 2015 and 2016 showed higher crown and leaf quality (*Qns*) for the individuals growing in the rural park (Qns_{2015} = 0.44, Qns_{2016} = 0.43) compared to the individuals in urban conditions (Qns_{2015} = 1.44, Qns_{2016} = 1.56). The values of chlorophyll *a* content index (*CCI*) were higher in the trees growing in the rural park (*CCI* = 25.914) than in the urban environment (*CCI* = 16.290). The performance of assimilation organs was evaluated through the maximum fluorescence yield (*Fv/Fm*) and electron transport rate (*ETR*) at both sites. During the years 2015 and 2016, there were measured higher values in the rural park (Fv/Fm_{2015} = 0.828, Fv/Fm_{2016} = 0.820) than in the town (Fv/Fm_{2015} = 0.823, Fv/Fm_{2016} = 0.772). Higher *ETR* values were measured on trees in the urban area (ETR_{2015} = 47.345, ETR_{2016} = 65.284) and lower in the park area (ETR_{2015} = 36.832, ETR_{2016} = 59.495). The urban locality demonstrated higher contents of Cu, Zn, Fe, Pb, Na and Ca elements in tree leaves compared to the rural park. The adaptability index (*Ia*) values indicate an average adaptability of the Norway maple to the urban environment (Ia_{2015} = 1.93, Ia_{2016} = 2.13) in comparison with a good adaptability in the rural park (*Ia* = 0.8–1.6).

Keywords

adaptability, assessment, compared settlements, Norway maple

Introduction

Continually worsening climate conditions in cities and towns represent a deteriorating environment for the growth of trees and for the performance of their ecological, environmental and social functions. Qualitative evaluation of tree response to extreme climatic conditions and to the associated alterations in the trees growth habitats is an important part of care for urban and historical greenery. The urban environment represents a wide spectrum of stress factors with severe negative effects on urban vegetation. Long-lasting summer dry periods with high air temperature and greenhouse gases presence cause the urban heat-island effect (Douglas, 2012). Wet and dry deposition of emissions, water and nutrient deficiency in urban soils, have an impact on photosynthetic disturbance, leaves injury pigment content changes (Petrova et al., 2014), growth and biology changes in urban trees

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(Leuzinger et al., 2010). Stress circumstances should be assessed at different layers of biological systems, with using macroscopic traits, physiological and/or biochemical markers. Bio-indication is a complicated process requiring a comprehensive solution. Tree assessment in urban conditions has a historical background and it is closely related to environmental properties. The quality of city green areas and their tree components was significantly influenced in the period of industrial boom in the 70`s–80`s of the 20^{th} century. The relationship between trees and their environment is evaluated at two levels: trees as bio- indicators of environmental quality and/or tree quality and growth patterns as reflection of environmental quality. Both methods have a reciprocal effect and it is difficult to separate them (Bernatzky, 1978; Innes, 1990; Supuka et al., 1991). Another method describes tree adaptability assessment based on terpene compounds analyses from conifer tree needles grown in urban green space conditions (Supuka, et al., 1997). Comprehensive assessment of tree adaptability based on morphological traits and selected ecology physiology markers has been published by Uhrin and Supuka (2016). Nowadays, tree adaptability processes are studied on the physiological and genetic level. Dehydrin gene is associated with the European beech (*Fagus sylvatica* L.) tolerance to drought and at the same time this gene is significantly associated with chlorophyll fluorescence parameters considered as stress markers (Krajmerová et al., 2017).

Stress effect and tree adaptability to changed environment are often assessed through chlorophyll fluorescence measurement a suitable non-destructive method operating on tree leaves (Kmeť, 1999). Chlorophyll *a* fluorescence has been described by Kalaji et al. (2016) as an important tool for monitoring the physiological state of plants growing under environmental stress conditions. This method is reliable and it works with portable instruments allowing measurement also under field trial conditions. Collective of authors have closely specified the usability of the method, the processes of measurement plant responses to various stress factors such as drought, increased temperature, salinity, nutrient deficiency, heavy metals. Many questions of methodological approaches, instrument types used, specific measurement problems, and evaluations of the results obtained have been published in another paper (Kalaji et al., 2017). Summarizing, the chlorophyll fluorescence method is fast, non-destructive, and it currently has a wide usage area. The results are representative in plant research under influence of abiotic stress.

The method of chlorophyll *a* fluorescence was applied during the assessment of the beech and spruce trees in forest stands (Kmeť, et al., 2009). It has been found, that stress from drought, salinity and increased UV-B radiation has harmful effects on photosynthesis rate in many plant species (Urban et al., 2006). Efficiency and stability of PSII photosynthetic systems are very important for operation of the whole photosynthetic apparatus. Active UV-B radiation can damage PSII system and decrease the photosynthesis effectiveness. Decreased yield of photosynthesis is reflected in reduction of fundamental photochemical chain of PSII (Haapala et al., 2010; Castle et al., 2011; Day et al., 2001). Operation of PSII system can be evaluated by chlorophyll fluorescence measurement. Growth inhibition is very often observed in many plant species due to high UV-B radiation and this inhibition is accompanied by reduction of photosynthetic capacity (Singh et al., 2012; Möller, 2001).

The aim of this article is a qualitative assessment of crown destruction and leaves injury in Norway maple (*Acer platanoides* L.) as well as chlorophyll *a* content and accumulation level of alochtonous elements in assimilation organs of this specimen grown in environmentally loaded environment and comparison of the obtained values with the corresponding ones for unloaded environment. The study was performed in the Nitra town conditions in comparison to the rural park in Nová Ves nad Žitavou, Slovakia. The tree adaptability to changed urban environment was assessed through visual morphology and physiological ecological traits.

Materials and methods

Study area and assessed woody plants

The aim of the research was to assess the adaptability of Norway maple (*Acer platanoides* L.) growing in urban environment in comparison to rural park condition. For study, the Nitra town was chosen as a locality environmentally loaded predominantly from cars' emissions, with the investigated trees growing along the busy transport road Tr. A. Hlinku. As a relatively non-loaded locality for comparison, there was chosen the rural historical park in Nová Ves nad Žitavou village, about 25 km east of Nitra. At both study localities, the assessment was carried out on three individuals of Norway maple. These three individuals assessed were almost similar in age of 50−70 years and the average high of 10−14 m. The study was performed in 2015 and 2016, repeated three times during the growing season in each year, specifically in the turn of June–July, in late August and in the turn of September–October. For tree assessment, there were used four methodical approaches: a) visual assessment of trunk, crown and leaf damage and destruction, b) values of leaf chlorophyll content, c) chlorophyll *a* fluorescence expressed in *Fv/Fm* and *ETR* parameters, d) content of heavy metals and biogenic elements in tree leaves. The results obtained were statistically evaluated and finally processed into the fusion Index of adaptability (*Ia*) for each assessed tree individual according to the two studied localities. More detailed methods have been described in a published article and in a doctoral thesis (Uhrin and Supuka, 2016; Uhrin, 2017).

Methods for visual assessment

For the assessment of the assimilation organs quality and level of crown destruction, there were the following indicators: defoliation, mortification of crown and evaluation of leaves necrosis. Levels of crown defoliation were evaluated according to the methodology by PEJCHAL (1995), INNES (1990), and SUPUKA et al. (1991) with a point scale ranging from 0 (no loss of foliage) to 4 (total loss of foliage). Also the level of dieback of the crown (PEJCHAL, 1995) and the degree of leave necrosis (SUPUKA et al., 1991) were assessed. For the assessment of the mentioned features there was used the following classification scale: 0 – no occurrence, 1 – occurrence by 25%, 2 – occurrence 26–50%, 3 – occurrence 51–75%, 4 – occurrence 76–100%.

For the myco-destructive evaluation and expression of mechanical damage, there were assessed three indicators: mechanical impacts, cavities and fungi, and wounds callusing as a reaction to mechanical damage. These indicators were assessed in range from 0 to 4, where 0 represented the lowest destructive expression and 4 the highest one. Mechanical damage was classified according to the type of pests (HRUBÍK and TKÁČOVÁ, 2004). Moreover, we have also included the trunk injury, roots injury, branches injury, and frost cracks (BERNATZKY, 1978), that were assessed according to a points evaluation system by PEJCHAL (1995) in the range from 0 (lowest level of influence) to 4 (highest influence). To each point values, a percentage rating, defining an exact scope of the burst expression was assigned. The incidence of cavities and fungi, as one of the biotic pest's types, was assessed according to HRUBÍK and TKÁČOVÁ (2004). Trunk cavity damage was assessed as an estimate, as well as mechanically, by inserting a hard wire into the trunk or branch cavity (GÁPER, 1998; GÁPER and GÁPEROVÁ, 2009). Callusing of wounds was evaluated by the callus width measurement that was put in relation to the total surface of wounds area in cm^2.

The results were converted into a qualitative index according to the modified formula (SUPUKA et al., 1991).

$$Q_n = \frac{\sum A_i . x_i + \sum B_i . x_i + \sum C_i . x_i}{\frac{\sum x_i}{\sum z_i}}$$

where Q_n is quality index of the n-th plants; A_i, B_i, C_i.... N_i are type and character of evaluated feature of i-th quality; x_i is the number of evaluated plants on the studied site; z_i is the number of rated characteristics.

Assessment of chlorophyll *a* content

Leaf chlorophyll *a* content was measured in 2016 during three study periods of growing season at the same time as the chlorophyll *a* fluorescence was measured. Both parameters were measured on ten chosen leaves in crown of each tree individual and in both study localities according to the standardised approaches. Measurement of chlorophyll content was performed with a portable chlorophyll-meter CCM 200 (Opti-Sciences, Inc., Hudson, NH 03051, USA) based on light absorbance measurement at double wavelength (red spectrum – 620 nm and blue spectrum – 940 nm). Measured outputs are indicated as Chlorophyll content index (CCI), with the obtained results expressed as relative values. The statistical files were tested among themselves for significance of differences between obtained results by the analysis of variance (ANOVA-test). More detailed methods, measurement and evaluating processes are described in other articles (UHRIN and SUPUKA, 2016; UHRIN, 2017).

Measurement of leaf chlorophyll *a* fluorescence

Assessment of chlorophyll fluorescence was performed by non-destructive method of tree leaves in the field conditions of the studied localities. The measurement was done by a pulse fluorimeter instrument FMS-2 (Fluorescence Monitoring System, Hansatech, GB) and the basic parameters resulting from the fluorescence induction curve of chlorophyll *a* were evaluated. The measurement was performed after a 30-min. adaptation of assimilation organs to darkness with the use of a leaf clamp chamber with a 7-mm diameter saturation aperture (KMEŤ et al., 2009; UHRIN and SUPUKA, 2016). In 2016, we decided to measure chlorophyll *a* fluorescence also directly without 30 min. obscuring tree leaves (in two measurement modules it meant dark-adapted and light-adapted leaves) in both studied localities. For measurement, the script with the following characteristics was set up: WAIT = 10.0 s (period of measurement fluorescence signal prior to light pulse); *Fv/Fm* = 2.5 s (measurement of F_0 and *Fm* during 2.5 s period of duration of high-frequency recording of fluorescence signal, during which the saturation pulse set at the maximum level app. 20,000 μmol m^{-2} s^{-1} with duration 0.8 s was applied. ACT – actinic light intensity was 500 μmol m^{-2} s^{-1}. A Halogen lamp with a 594-nm amber modulating beam frequency was used as a light source. We used a Halogen lamp OSRAM 64255 – 8 V, 25 W units.

Using the instrument with these set-up parameters there were measured 10 leaves of all three chosen trees around the crown perimeter at a 1.5−2.5 m height above the ground. All the measured values were continually saved to the control unit of the FMS-2 instrument and subsequently exported and evaluated by software MODFLUOR 32. The measured physiological parameters *Fv/Fm* were statistically evaluated by the analysis of variance (ANOVA) testing the significance between the two assessed study localities and the three assessed periods. Values of *Fv/Fm* parameters were measured – maximal yield of the photochemical processes PSII and *ETR*- relative speed transport of free electrons of the photochemical processes PSII.

Assessment of heavy metals and biogenic elements in tree leaves

Tree leaves sampling was done in the second part of August 2016 during sunny weather without rain. The leaves were not washed with water. They were dried at a room temperature and then in a thermo-chamber (Binder model FD 115) at 105 °C up to a constant weight. The dried leaves were milled into powder and stored in plastic bags. The dried and pulverized biological samples (1.0 g) were mineralized in a closed system of microwave digestion using Mars X-Press 5 (CEM Corp., Matthews, NC, USA) in a mixture of 5 mL HNO_3 (Supra PUR, Merck, Darmstadt, Germany) and 5 ml de-ionized water (0.054 mS cm^{-2}) from Simplicity 185 (Millipore SAS, Molsheim, France). From solution, there were analyzed chosen elements (Cu, Zn, Mn, Fe, Pb, Cd, K, Na, Ca, Mg and P) mainly with the aid of an atomic absorption spectrophotometer F-AAS (Varian Inc., Mulgrave, VIC, Australia). The detailed methodical approach and analyze processes are described in other articles (Árvay et al., 2015; Uhrin, 2017). Results are given in mg kg^{-1} of leaf dry matter.

Overall assessment of tree adaptability to changed urban environment

All the partial approaches, analytical methods and results obtained were used for the overall assessment including: a) visual estimation of trunk, crown and leaf damage and destruction, b) values of leaf chlorophyll content, c) chlorophyll *a* fluorescence expressed in *Fv/Fm* and *ETR* parameters, d) content of heavy metals and biogenic elements in tree leaves. The determined values were compared with the approved rating limits and calculated as tree adaptability index (*Ia*) which includes partial indexes according to the parameters described in the previous paragraph points a)–d) and shown in Table 1. The overall categorization of the adaptability index values is according to the following five points: 0 – The woody plant shows a high adaptability to the examined environment. The tree does not demonstrate damage symptoms. Its photochemical efficiency is above-average, with high chlorophyll *a* content. The biogenic elements contents in leaves are under the approved rating limits, with the index rated within an interval of 0.0–0.8; 1 – The woody plant is adaptable to the examined environment. The tree demonstrates slight damage to the above-ground vegetation organs. Its photochemical efficiency is average, with slightly decreased chlorophyll *a* content. The biogenic element contents in leaves reach a maximum representing twofold of the approved rating limits. The index is rated within an interval of 0.9–1.6; 2 – The woody plant's adaptation to the examined environment is average. The tree individual demonstrates serious damage to its above ground vegetation organs. The photochemical efficiency and chlorophyll *a* content are markedly decreased. The biogenic element content in leaves reaches a maximum representing from two up to three times of the approved rating limits. The index is rated within an interval of 1.7–2.4; 3 – The woody plant's adaptation to the examined environment is under average. The tree individual demonstrates heavy damage to the above ground vegetation organs without auto-regeneration ability. The photochemical efficiency and chlorophyll *a* content are markedly decreased. The biogenic element content in leaves reaches a maximum from two up to three times of the approved rating limits. The index is rated within an interval of 2.5–3.2; 4 – The woody plant is not adaptable to the examined environment. The tree individual demonstrates very heavy damage to the above ground vegetation organs without auto-regeneration ability. The photochemical efficiency and chlorophyll *a* content are markedly decreased under the functional limits. The biogenic element content in leaves reaches a maximum from two up to three times of the approved rating limits. The index is rated within an interval of 3.3–4.0.

Results and discussion

Visual assessment

The tree individuals assessed in 2015 demonstrated high degrees of tree crown damage, leaf necrosis and a considerable degree of defoliation. As early as during the first assessment period in the urban environment, an advanced phase of the crowns margin breaking was identified. In the tree individuals growing in the unloaded rural park, this phenomenon was not present, only slight leaves necrosis was observed (Table 2).

In 2016, the level of damage was slightly worsened in the urban environment, with more distinct leaf necrosis traits showing more leaf damage in comparison with the previous year (Table 3). The trees in the unloaded rural park demonstrated the same damage forms, but in lower degrees in comparison with 2015. The level of mechanical damage and tree stem wounds callusing were similar in both studied years.

Tree individuals of Norway maple (*Acer platanoides* L.) demonstrated high differences between the compared localities in all the observed and assessed characters of crown, leaf, trunk and physiological traits. The damage level in the city environment took an increased course from the first year up to the second study year. The main reason should be considered the worsened environmental conditions predominantly water deficiency, high temperature in summer periods and generally drought climate in the Nitra town in 2015 and also 2016 reported also in other articles (Uhrin and Supuka, 2016; Uhrin, 2017).

Table 1. Overall assessment of tree adaptability to changed city environment

Marker	Mark	Index	Range of values	Description of expression
Qualitative index	Q_n	0	*Qn* = 0–0.8	No or rarely identified damage to tree crowns and leaves
		1	*Qn* = 0.9–1.6	Slightly damaged tree crowns and assimilatory organs
		2	*Qn* = 1.7–2.4	Extensive damage to tree crowns and assimilation organs
		3	*Qn* = 2.5–3.2	Highly extensive damage on tree crowns and assimilation organs
		4	*Qn* = 3.3–4.0	Complete extensive damage on tree crowns and assimilation organs
Chlorophyll content index	*CCI*	0	P > 0.05	Differences between trees on loaded and unloaded localities are statistically not significant.
		1	P ≤ 0.05	Differences are statistically significant.
		2	P ≤ 0.01	Differences are statistically more significant.
		3	P ≤ 0.001	Differences are statistically high significant.
		4	P ≤ 0.0001	Differences are statistically very high significant.
Maximum fluorescence yield	*Fv/Fm*	0	*Fv/Fm* > 0.850	Very highly fluorescence yield. Median value of F_v/F_m parameter is over the optimum.
		1	*Fv/Fm* = 0.850 – 0.801	High fluorescence yield. Median value of F_v/F_m parameter is slightly reduced.
		2	*Fv/Fm* = 0.800 – 0.751	Decreased fluorescence yield. Median value of F_v/F_m parameter is significantly reduced.
		3	*Fv/Fm* = 0.750 – 0.701	Low fluorescence yield. Median value of F_v/F_m parameter is under limit of stress significance.
		4	*Fv/Fm* ≤ 0.700	Very low fluorescence yield. Median value of F_v/F_m parameter is strongly under limit of stress significance.
Electron transport rate	*ETR*	0	*ETR* ≥ 126	Woody species has high electron transport speed.
		1	*ETR*= 125.9–105	Woody species has average electron transport speed.
		2	*ETR* = 104.9–84	Woody species has below average electron transport speed.
		3	*ETR* = 83.9–63	Woody species has low electron transport speed.
		4	*ETR* ≤ 62.9	Woody species has very low electron transport speed.
Content of the alochtonous and biogenic elements	*Op*	0	*Op* ≤ LV	Element content in analyzed tree leaves is under limit value (LV).
		1	*Op* = LV – 1.5 × LV	Element content in analyzed tree leaves is up to 1.5 times the limit value.
		2	*Op* = 1.5 x LV – 2 × LV	Element content in analyzed tree leaves is up to 2.0 times the limit value.
		3	*Op* = 2 x LV – 2.5 × LV	Element content in analyzed tree leaves is up to 2.5 times the limit value.
		4	*Op* ≥ 2.5 × LV	Element content in analyzed tree leaves is above 2.5 times the limit value.

Table 2. Visual assessment of Norway maple (*Acer platanoides* L.) in 2015

Locality	Term of measurement	Cd	Dc	Ln	Md	Ic	Wcs	*Qn*	*Qns* (2015)
Town	June	1.3	1.7	1.3	0.0	0.0	3.3	1.28	
Town	August	1.3	1.7	2.3	0.0	0.0	3.3	1.44	1.44
Town	October	1.7	2.0	2.7	0.0	0.0	3.3	1.61	
Park	June	0.3	0.3	0.3	0.7	0.0	0.7	0.39	
Park	August	0.3	0.3	0.7	0.7	0.0	0.7	0.44	0.44
Park	October	0.3	0.3	1.0	0.7	0.0	0.7	0.50	

Cd, crown defoliation; Dc, crown dieback; Ln, leaf necrosis; Md, mechanical damage; Ic, incidence of cavities in trunk or branches; Wcs, wound callusing; *Qn, Qns,* quality index.

Table 3. Visual assessment of Norway maple (*Acer platanoides* L.) in 2016

Locality	Term of measurement	Cd	Dc	Ln	Md	Ic	Wcs	*Qn*	*Qns* 2016
Town	June	1.7	1.7	1.3	0.0	0.0	3.3	1.33	
Town	August	2.3	1.7	2.0	0.0	0.0	3.3	1.56	1.56
Town	October	2.3	1.7	3.0	0.0	0.0	3.7	1.78	
Park	June	0.0	0.0	0.0	1.3	0.0	0.7	0.33	
Park	August	0.0	0.3	1.0	0.7	0.0	0.7	0.44	0.43
Park	October	0.3	0.3	1.0	0.7	0.0	0.7	0.50	

For key to abbreviations see Table 2.

Chlorophyll *a* content

An overall multi factorial analysis of variance performed on the leaf chlorophyll *a* content showed differences between the compared localities and between the studied years. During 2016, higher levels of chlorophyll *a* content were determined in trees growing in the rural park in comparison to the urban environment, within all the three periods assessed. The chart of chlorophyll *a* content in leaves confirmed a low stability of photosynthetic active pigments in tree individuals in urban conditions. This was also visible from the variation coefficient, exhibiting a wide scattering. Higher rate of chlorophyll *a* production was also obvious from the median of the statistical set for the trees grown in the rural park where higher production values were indicated during the whole growing season (Table 4).

Assessment of chlorophyll *a* fluorescence

The values of the assessed parameter of fluorescence yield in the system PS II expressed through *Fv/Fm* showed an expressive decrease during the second measuring period, caused by extremely dry conditions in the summer 2015 in both localities. The statistical significance between the localities was very low during the first and the second measurement period but this significance increased rapidly in the third assessment period. In 2016, the measured values exhibited a relatively stabilized trend decreasing from the first to the last measurement period. The differences were most significant in the second study period.

The general characteristics of the statistical set showed relatively balanced values of variation coefficient. Similar values were observed for standard deviations between the localities in 2015 (Table 6). The fluorescence yield in urban conditions varied from 0.859 to 0.757. On the other hand, higher values of maximal photochemical efficiency of photosystem II were measured in trees in the rural park, ranging from 0.862 to 0.743. In 2016, the differences between the localities were higher, which also corresponded to the median values. The dispersion range of the statistical sets was higher especially in the second measuring term. The obtained values were from 0.841 to 0.690 in the urban conditions and from 0.851 to 0.732 in the park conditions.

The results of statistical analysis and P-limit values show a high statistical significance in the indicated differences both between the localities and between the measuring dates of the chlorophyll *a* content. The comparisons of the selected median values between the localities confirmed high differences in these median values for all the three studied periods (Table 5).

Table 4. Descriptive statistics of the chlorophyll *a* content values for *Acer platanoides* L. in 2016

Term of measurement	Locality	Median	Standard deviation	Variance coefficient	Min	Max	Range
June	Town	20.887	5.096	24.398%	10.7	31.5	20.8
	Park	29.653	5.224	17.618%	20.1	38.0	17.9
August	Town	14.293	2.471	17.294%	9.8	20.1	10.3
	Park	30.953	7.920	25.589%	16.0	40.8	24.8
October	Town	14.090	1.858	13.186%	10.7	17.8	7.1
	Park	17.137	1.797	10.486%	13.7	20.9	7.2
Summarized	Town	16.290	4.342	26.659%	9.8	31.5	18.4
	Park	25.914	8.344	32.200%	13.7	40.8	27.1

Table 5. Analysis of variance and comparison of median values for chlorophyll *a* content in Norway maple leaves (*Acer platanoides* L.) in the two localities in 2016

Statistical limits	Measurement			
	June	August	October	Jointly
P-value	<0.0001****	<0.0001****	0.001***	<0.001***
F-ratio	43.29	120.94	41.68	94.21

***P ≤ 0.001 – statistically high significant differences, ****P ≤ 0.0001 – statistically very high significant differences.

Table 6. Descriptive statistics of the *Fv/Fm* parameter in *Acer platanoides* L. in 2015 and 2016

Term of measurement	Locality	Median	Standard deviation	Variance coefficient	Min	Max	Range
June 2015	Town	0.841	0.0085	1.015%	0.826	0.859	0.033
	Park	0.844	0.0102	1.213%	0.825	0.862	0.037
August 2015	Town	0.806	0.0203	2.520%	0.757	0.832	0.075
	Park	0.804	0.0282	3.514%	0.743	0.847	0.104
October 2015	Town	0.820	0.0148	1.803%	0.789	0.848	0.059
	Park	0.835	0.0074	0.892%	0.820	0.847	0.027
Summarized 2015	Town	0.823	0.0210	2.554%	0.757	0.859	0.102
	Park	0.828	0.0247	2.988%	0.743	0.862	0.119
June 2016	Town	0.795	0.0290	3.646%	0.739	0.841	0.102
	Park	0.836	0.0099	1.184%	0.812	0.851	0.039
August 2016	Town	0.762	0.0310	4.060%	0.720	0.821	0.101
	Park	0.824	0.0096	1.167%	0.806	0.842	0.036
October 2016	Town	0.758	0.0316	4.167%	0.690	0.796	0.106
	Park	0.793	0.0387	4.885%	0.732	0.828	0.132
Summarized 2016	Town	0.772	0.0344	4.460%	0.690	0.841	0.151
	Park	0.820	0.0245	2.993%	0.732	0.851	0.119

The results of statistical analysis show statistically significant differences between the statistical sets for both localities in 2015. In 2016, ANOVA identified very high significant differences between the localities, see Table 7.

The measuring data for the parameter of electron transport speed (*ETR*) in the assessed trees were higher in the urban conditions than in rural park. The general course of values in both localities in 2015 showed a decreasing

Table 7. Analysis of variance of the *Fv/Fm* parameter in *Acer platanoides* L. in the two sites in 2015 and 2016

Statistical limits	Year	Measurement			
		June	August	October	Jointly
P-value	2015	0.6855	0.6500	<0.0001****	0.0147*
F-ratio	2015	0.87	0.17	25.63	2.12
P -value	2016	<0.0001****	<0.0001****	0.0003***	<0.0001****
F- ratio	2016	54.15	106.81	14.91	116.42

*$P \leq 0.05$ – statistically significant differences, ***$P \leq 0.001$ – statistically high significant differences, ****$P \leq 0.0001$ – statistically very high significant differences.

tendency, see Table 8. In 2016, the measured values again followed a fluent decreasing course. The differences between the localities were slightly above the border threshold of statistical significance (Table 9). Higher values of *ETR* in the examined tree individuals were identified in the urban conditions. There was the reason why we decided to measure the chlorophyll *a* fluorescence also directly, without 30 min. obscure of tree leaves (in the two measurement modules this meant dark-adapted and light-adapted leaves) in both the studied localities. Our intention was to acquire more outputs about the actual course of electron transport speed and the actual efficiency in leaf photochemical reactions in the studied trees. All the measurements including modulated form are given in Fig. 1.

During growing season 2015, the values in the urban environment varied from 111.51 to 13.23. In the rural park, the levels were lower, ranging from 88.41 to 12.18. In 2016, the statistical sets exhibited higher medians and less scattered values in comparison to the previous year. The values in the urban environment ranged from 80.64 to 44.31 while in the rural park, there were identified values in the range from 93.87 to 33.39. A survey of statistical characteristics is presented in Table 8. The results of a statistical test performed in 2015 on the median showed a high significance in the first two measurement terms and significance in the third measurement term.

In 2016, the differences between the median values were identified statistically significant for the first two measuring terms and high significant for the third term. A summary of the results is given in Table 9.

The obtained results showed higher values of the actual (none modulated) electron transport speed in the trees grown in the rural park. This may reflect higher performance of the photochemical processes, in consistence with higher values of *ETR* parameters measured in the trees in the urban environment after 30 min. leaf adaptation on light, reflecting the photo-inhibition processes in photochemical active tissues in the assimilatory organs. The fluorimeter FMS-2 indicated higher values of this parameter in case of the efficiency of the photo synthetically active light use (*ΦPSII*) in PS II systems without distinguishing the type of photochemical reaction. The results of visual assessment showed significant deviations in the quality of assimilatory organs and in the destruction status for the tree crowns in the urban environment in comparison to unloaded rural park. Therefore, this woody species may be recognized as relatively stable and adaptable in urban greenery and street alleys in the assessed urban environment. It is a realistic postulation, in accordance with many publications confirming that progressive multi-factorial stress impact in urban areas reduces vitality, growth and life span of trees (Grabosky and Gilman, 2004; Saebo et al., 2005; Chen et al., 2017).

Content of heavy metals and biogenic elements in leaves of the model woody plant

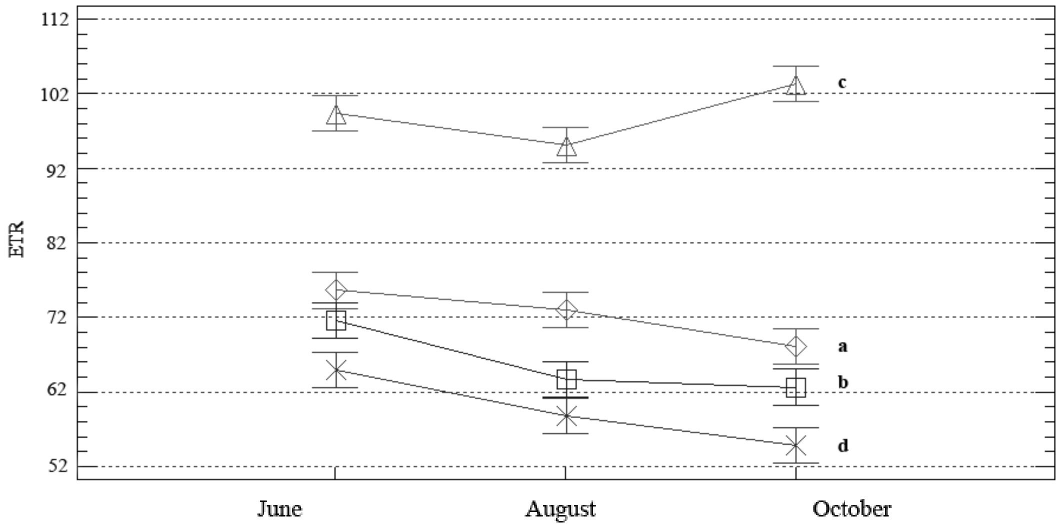
The assessed trees showed only small amounts of heavy metal in their leaves. Besides manganese, the higher heavy metals values were identified in the trees growing in the urban environment. The values of biogenic elements, namely potassium, nitrogen, calcium and phosphorus, reached levels in the tree leaves grown in the urban conditions. On the other hand, the higher magnesium content was determined in leaves of the trees growing in the rural park.

A summary review of the elements analyzed in leaves for all the assessed trees in the two localities; urban area and rural park, is given in Table 10. The presented values are under the approved limits for all the analyzed elements.

Summary assessment of tree adaptability for urban environment

Table 11 shows the final assessment of tree adaptability encompassing the comprehensive partial valuation approaches described in the methodical chapter. The results present an assessment of Norway maple (*Acer platanoides* L.) trees growing in the urban environment of the Nitra town, performed in 2016. The final assessment used all the partially valuated traits and their indexes *Iap* for calculation of the general average index $Ia_{(2016)}$.

The final adaptability index ($Ia_{(2016)} = 2.13$) indicated that the assessed trees were relatively adaptable to the actual urban conditions of the Nitra town. The worst quality indexes were achieved for the traits of chlorophyll *a* content and photochemical efficiency, showing markedly decreased values in comparison to the unloaded



Terms of measuremeut

Fig. 1. Development of *ETR* values in *Acer platanoides* L. in 2016. Locality: a – Nitra town light-adapted, b – Nitra town dark-adapted, c – Park light-adapted, d – Park dark-adapted. The data represent arithmetical means of *ETR*. Vertical lines indicate a 95% confidence interval.

Table 8. Descriptive statistics of the *ETR* in *Acer platanoides L*. in 2015 and 2016

Term of measurement	Locality	Median	Standard deviation	Variance coefficient	Min	Max	Range
June 2015	Town	75.712	16.7693	22.149%	50.19	111.51	61.32
	Park	53.515	19.7996	36.998%	22.47	88.41	65.94
August 2015	Town	45.507	12.2901	27.007%	31.29	75.60	44.31
	Park	32.578	11.4779	35.232%	14.49	56.70	42.21
October 2015	Town	23.268	6.3319	27.213%	13.23	34.23	21.00
	Park	21.369	6.0564	28.342%	12.18	36.12	23.94
Summarized 2015	Town	47.345	25.7095	54.303%	13.23	111.51	99.33
	Park	36.832	18.2649	49.590%	12.18	88.41	74.97
June 2016	Town	69.546	7.3193	10.525%	53.76	80.64	26.88
	Park	64.907	12.4468	19.176%	43.05	93.87	50.82
August 2016	Town	63.662	9.0874	14.275%	44.31	74.34	30.03
	Park	58.753	6.3493	10.807%	47.25	69.58	22.33
October 2016	Town	62.643	9.8615	15.742%	46.62	79.17	32.55
	Park	54.824	11.3176	20.644%	33.39	76.23	42.84
Summarized 2016	Town	65.284	9.2419	14.157%	44.31	80.64	36.33
	Park	59.495	11.0800	18.623%	33.39	93.87	60.48

environment. The contents of analyzed elements in tree leaves did not exceed the approved limits, therefore this mark was valuated as zero.

The damage level to the urban environment in the Nitra town was confirmed by other authors performing research in the concerned conditions. Petrova et al. (2014) studied

Table 9. Analysis of variance performed on the *ETR* parameter in *Acer platanoides* L. in both sites in 2015 and 2016

Statistical limits	Year	Measurement			
		June	August	October	Summarized
P -value	2015	<0.0001****	0.0001****	0.2400	0.0018**
F-ratio	2015	21.96	17.73	1.41	10.00
P-value	2016	0.0838	0.0184*	<0.001***	0.0002***
F-ratio	2016	3.10	5.88	8.14	14.49

*P ≤ 0.05– statistically significant differences; **P ≤ 0.01– statistically more significant differences; ***P ≤ 0.001– statistically high significant differences; ****P ≤ 0.0001– statistically very high significant differences.

Table 11. General and final assessment of adaptability of Norway maple (*Acer platanoides* L.) trees from the Nitra town environment, performed in 2016

Measurement	*Q*		*CCI*		*Fv/Fm*		*ETR*		*Op*	*Iap*	$Ia_{(2016)}$
	h	k	h	k	h	k	h	k	k		
June 2016	1.33	**1**	<0.0001	**4**	0.795	**2**	69.546	**3**	**0**	2.00	
August 2016	1.56	**1**	<0.0001	**4**	0.762	**2**	62.662	**4**	**0**	2.20	2.13
October 2016	1.78	**2**	0.0010	**3**	0.758	**2**	62.643	**4**	**0**	2.20	

Q, quality index value; *CCI*, chlorophyll *a* content index; *Fv/Fm*, maximal fluorescence yield; *ETR*, relative speed of electron transport; *Op*, rate of exceeding the limit element content in leaves; *Iap*, partial adaptability index; $Ia_{(2016)}$, final adaptability index for Norway maple in 2016; h, calculated adaptability index for trait; k, category of adaptability.

ecology of physiological response in three model woody species *Acer platanoides* L., *Aesculus hippocastanum* L. and *Betula pendula* Ehrh. in environmentally loaded conditions and compared differences in their leaf contents of the photo-chemically active pigments such as chlorophyll – *a b* and carotenoids.

In calculation of the adaptability index, there was taken into account the *ETR* parameter values measured after 30 min. of leaf tissue adaptation to darkness (obscuration). The acquired results point to the presence of a photochemical process acting as active defense against leaf tissue oxidation (Melis, 1999; Demming and Adams et al., 1998; Adir et al., 2003; Singh et al., 2012). Therefore, many other authors consider this data as indicative in the field of drought-induced stress caused by changes to the soil properties (Johnson and Thornley, 1987; Coder, 1998; Tworkoski and Scorza, 2001; Day et al., 2010).

Conclusions

The acquired research results present a new knowledge and possibilities for tree adaptability assessment in changed urban environment, exemplified on a model representing the Nitra town's conditions. As expected, the lower damage rates to the assimilative organs were identified at the studied tree individuals grown in unloaded environment of rural park. In the rural park, there were measured the highest values of *Fv/Fm* parameter. The values of *ETR* parameter measured after a 30 min. obscuration were higher in the urban environment, but higher without obscure in park environment. This knowledge concerning the *ETR* parameter results is surprising, therefore tree adaptability assessment based on this trait needs more research in the future.

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Table 10. Content of heavy metals and biogenic elements in leaves of *Acer platanoides* L. in the two study sites in 2016

Locality	Sample	Element content in tree leaves (mg kg^{-1})										
		Cu	Zn	Mn	Fe	Pb	Cd	K	Na	Ca	Mg	P
Park	1	4.00	8.20	164.70	72.40	2.00	1.10	11,496.70	184.30	44,373.80	2,832.50	2,847.60
	2	5.70	11.40	221.70	56.00	3.10	4.30	14,012.70	183.10	34,573.60	2,343.30	4,044.80
	3	3.00	7.90	125.40	80.30	3.50	1.31	11,676.80	185.30	30,613.70	1,980.20	3,199.60
Town	1	5.40	13.80	32.60	109.80	5.50	1.20	13,208.20	253.90	46,136.40	2,747.00	2,965.80
	2	6.50	14.00	61.70	118.00	4.80	1.03	8,352.10	265.00	60,232.10	2,138.70	2,393.00
	3	6.40	14.20	33.10	145.60	3.70	1.01	11,760.20	228.10	67,863.70	9,179.90	1,701.80

Sample 1, 2, 3 – three times repeated sampling for element content analyses.

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