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Assessment of Trees Vitality in Urban Landscape of Steppe Zone

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Abstract. During planning of green planting in cities, vital status of plants which make up the groups is taken into account first. The methods of assessment of morphological and physiological parameters of the vital status are the most widely used ones. In the process of work, the vitality of woody plants was evaluated under the impact of anthropogenic pressure in the framework of the physiological state, which is determined to a great extent by the content of chlorophylls in the leaves of trees. The content of green and yellow pigments was studied in the drought conditions of vegetative period for 8 species of trees which are common in green planting of cities in the South-East of Ukraine. Stable species (*Populus simonii* Carriér, P*opulus* × *canadensis* Moench) respond by increase in the content of chlorophylls at maximum air temperatures during the growing season. Nonsufficient-stable species show significant effect of the amount of rainfall on the changes in chlorophyll content in leaves, which is the evidence of their adaptive capacity. Deterioration of the functional state of trees in street and park planting compared to suburban territories was revealed, confirmed by reduced chlorophyll content and increase in carotenoids. For the further introduction in the urban greening of industrial cities of steppe zone, the models of influence of the meteorological factors on the content of green pigments in the leaves of *Polulus simonii* and *Acer pseudoplatanus* L. are proposed.

Key words: trees, urban environment, total chlorophylls, carotenoids, meteorological factors, exhaust gases.

Introduction

Trees as a part of urban plantation perform a number of functions: they decontaminate the air, absorb CO_2, enrich the atmosphere with oxygen etc. However, in the conditions of big industrial cities, trees are affected by environmental pollutants. The air pollution of the territories of industrial-urban centres has on a complex character. In the residential areas of the city the main source of pollution are motor cars, in the industrial zones - the enterprises of thermal power, metallurgical, chemical, processing and mining industry. The result of car engines' running is the release of exhaust gases CO_2, N_xO_y, SO_2, hydrocarbons, aldehydes, soot and benzo(a)pyrene (Hopke, 2009). Among industrial pollutants, sulfur dioxide and nitrogen oxides represent the gravest hazard for plants. Premature fall of leaves and needles occurs in woody plants affected by sulfur dioxide (Palau et all., 2009). The action of nitrogen oxides leads to chloroses of various types: brownish-black sections appear on the top and at the edges of leaves (Spellberg, 1998). The level of pollution of a certain territory of the city is determined by the distance from the main sources of contamination, the major directions of the wind rose, the topographic features and the city planning situation (Korshikov et al., 2005).

Specific conditions of the southeastern steppe with high temperatures in summer and low temperatures in winter seasons, strong winds and low rainfall are exacerbated in the urban areas. Almost all environmental components in the big city – atmosphere, flora, soil, relief, hydrographic network, groundwaters, – undergo changes. Anthropogenic factors affect the indicators of temperature, humidity, the formation of air masses and light conditions, which in general leads to the emergence of peculiar microclimate. Thermal, chemical, radiation, electromagnetic, light, sound, vibration factors etc. are the main negative urban factors. In the cities, they often act simultaneously, particularly with regard to the motorways with heavy traffic (Zhang et al., 2007; Nowak et al., 2006; Morgenroth & Östberg; Iqbal et al., 2015).

In Ukraine, the large number of major cities with powerful enterprises are situated on the southeast. It should be noted that specific conditions of the southeastern part of steppe zone of Ukraine with high temperatures in summer and low temperatures in winter seasons, strong winds and low rainfall and drought are additional stressed factors for plants at urban territories. In these settings, the durability and efficiency of urban tree plantations are diminished, that has negative environmental and economic impacts (Korshikov & Vinogradova, 2005). In this connection, the urgent task of ecological research is to monitor and diagnose the living condition of urban-steppe landscapes plantations of the steppe zone with the complex influencing negative anthropogenic and natural and climatic factors.

In order to determine the vitality of trees, different approaches are used (Johnstone et al., 2013) – from ocular estimate method of the general conditions of the individual on point scales (Suslova et al., 2013), biomorphological assessments of growth, development, phenorhythm types and reproductive ability (Korshikov & Krasnoshtan, 2012) to physiological and biochemical indicators of the activity of metabolic processes and concentration of functionally important compounds and metabolites in the leaves - plastid pigments, total nitrogen, soluble proteins, non-structural pigments, starch, lipids, etc. (Glibovytska et al., 2017). A wide range of these methods is able to give definitely comprehensive assessment of the vital state of plants. At the same time, in ecological investigations preferences are disposed to the separate test-parameters and express-methods, which characterize the most adequately the state of plants under specific conditions depends on the performance targets.

Besides this, the parameter of photosynthetic pigment concentration is widely used in the conditions of industrial contamination of the functional state of the woody plants. The similar studies are conducted to determine the drought resistance of plants thereby the plant reaction to the pollution is the same as the reaction of dehydration factor. Photosystems of chloroplast especially photosystem II, that contains light harvesting complexes of photosynthetic pigments, are too sensitive systems of deferential mesophyll cells, and their adaptability ensures the preservation of the photosynthetic apparatus and its restoration in case of damage (Morgenroth & Östberg, 2017). According to Bessonova et al. (2015), sum of chlorophylls is reduced by the action of car exhausts. Changes of the concentration of chlorophylls and carotenoids indicate the decrease in the plants' metabolic processes under stress (Uhrin & Supuka, 2016). For quantity assessment of plants gas resistance has been suggested air pollution tolerance index, for the calculation of which, in addition to the leaf water content indexes, pH of leaf tissue extract, the parameter of chlorophyll concentration is used (Tripathi et al., 2009).

The physiological aspects of vital status of woody plants under the stressed hydrothermal urban conditions during the vegetative period are not yet fully understood. The easternmost continental area of the steppe zone of Ukraine – Donetsk city draws the biggest attention from this side. A full-scale study of the viability of the urban tree plantations was conducted here ifn through inventory using the ocular estimate method (Suslova, 2013). In some works, the physiological indicators of trees' vitality in the cities of southeastern Ukraine were determined. For example, the vitality for certain species of the *Acer* genus was determined with the use of chlorophyll concentration without taking into account meteorological factors of the period under study (Korshikov & Vinogradova, 2005). Therefore, the study of the impact of the urban environment on the functional state of trees and prediction of its subsequent changes is relevant for the proper management and planning of green building in the steppe zone.

The goal of the work was the assessment of the vitality of trees in urban and industrial territories in the conditions of continental drought climate of the steppe zone depending on the dynamics of changes and quantitative determination of plastid pigments.

Materials and Methods

Research was conducted during two years (2012, 2013) in one of the largest industrial cities of southeastern Ukraine – Donetsk. The city is located between 48° 02′ north latitude and 37° 48′ east longitude. Monitoring sites 1 and 2 (m.s. 1, m.s. 2) are situated in the residential area of the city with inherent level of air pollution, which is formed by the fumes from mining, processing and metallurgical enterprises, but they differ in the content of individual ingredients.

M.s. 1 is located on the Kyivskyi avenue with intensive with heavy traffic and higher pollution, m.s. 2 – in the large green area of the Recreation and Entertainment Park with less level of pollution. According to the Sectoral State Archive of the Hydro-meteorological Service of Ukraine (Ukrainian hydrometeorological center), the total average daily concentration of SO_2, NO_2, dust, CO, formaldehyde at m.s. 1 was 2.175 and 2.102 mg/m^3 in the years of research, whereas mt.2 – 1.712 and 2.006 mg/m^3. It should be noted that the level of SO_2 content at the monitoring points in both years was within 0.2 MPC.

Higher total level of pollution on m.s. 1 was achieved due to the increased content of the basic ingredients of exhaust gases in both years of research: CO - 1,6925 and 1,6515 mg/m^3 and, particularly, NO_2 - 0,1771 and 0,1731 mg/m^3, which was 4.43 and 4.33 MPC, respectively. At m.s. 2, the CO content was 1.2451 and 1.5234 mg/m^3; NO_2 - 0.0967 and 0.1575 mg/m^3 (2.42 and 3.94 MPC). Besides this, at m.s. 1 it was established increased average daily concentrations of ammonia - 0.0730 mg/m^3 (1.82 MPC), phenol mg/m^3 - 0.0036 (1.20 MPC). All this testifies to a higher level of air pollution on the m.s. 1 - the central city highway, compared to the city park area (m.s. 2).

Control monitoring site (m.s. 3) is placed at a distance of 15 km from the town in the village of Tonenke. There are no urban and industrial impacts on the environment, and it is characterized by a small (background to this region) content of ingredients such as SO_2 (0.0050 and 0.0100 mg/m^3) and NO_2 (0.093 and 0.1060 mg/m^3).

Species widely used in greening of the city were studied during the growing season in 2012 and 2013 (from May to October), which differ on the hydrothermal conditions. As illustrated in Fig.1, the first year was prosperous for plants due to the temperature regime and falls amount, except of the drought autumn period, which was not typical for the steppe zone. The second year was characterized by the droughts in spring and summer, which is common for the climate of the South-East of Ukraine and less suitable for normal growth and development of trees. Monthly average temperatures, air humidity and rainfall were taken from the reports of the National Hydro-meteorological Center of Ukraine (Ukrainian hydrometeorological center).

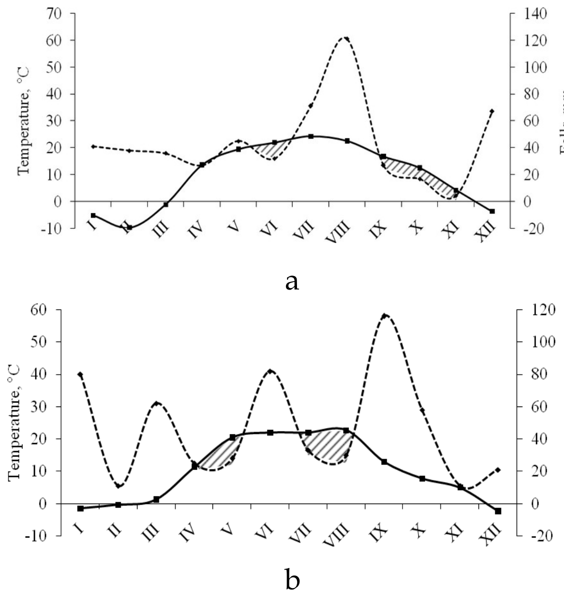

Fig.1. Hydrothermal conditions in the years of research in Donetsk: a – 2012, b – 2013.
- drought periods,
- dynamic of temperature during the year,
- dynamic of falls during the year.

Eight tree species of the *Aceracea*, *Salicaceae*, *Fabacea*, *Malvaceae* and *Oleaceae* genera were studied at three monitoring sites in different types of plantations: in the linear street plantations on the Kyivskyi avenue (m.s. 1), in the massive plantations in the Recreation and Entertainment Park (m.s. 2), plots in the field shelter belts and village plantations of v.Tonenke at control site (m.s. 3). We selected 7-8 even-aged model trees of each species with the most typical vital status for the plantations of monitoring sites.

General vitality of the plants was established under the ocular 8-point scale by Savelieva (1975), which is commonly used in the investigated area (Suslova et al., 2013; Polyakov et al., 2012). The scale is based on the criteria of the trunk and crown damages, inhibition of apical and lateral growths, drying of branches, dry tops, the presence of adventitious shoots, vegetative shoots on the trunk, coppice shoots, development on the trunk of trees fungi. We evaluated the absence of these criteria in plants as 8points. Their appearance and impact on the trees reduces the vitality of the plant from 7 to 1 point, complete drying of the whole tree and root system, the absence of shoots from the stump was assessed as 0 point.

We collected plants materials monthly in sunny windless weather from May to October. With the purpose of obtaining the average sample, leaves were sampled from 7-8 trees.

Chlorophylls and carotenoids were extracted in 80 % acetone in triplicate repetition. We determined solution absorbency (D) by spectrophotometer ULAB 108UV under the different wave length: 663 nm; 646 nm and 470 nm. Concentration of pigments of the extract (mg/l) was calculated by the Lichtenthaler equations (Shlyk, 1975), with the special extraction coefficient for each component:

$$C_{chl.a} = 12{,}21\ D_{663} - 2{,}81\ D_{646};$$
$$C_{chl.b} = 20{,}13\ D_{646} - 5{,}03\ D_{663};$$
$$C_{car} = (1000\ D_{470} - 3{,}27\ C_{chl.a} - 100\ C_{chl.b})/229.$$

We calculated quantity content of the chlorophyls a (*chl a*), chlorophyls b (*chl b*) and carotenoids (*car*) of plants material with counting of obtained concentration of pigments in the extract under volume of the extract (25 ml) and weighted amount of plant material (0.1-0.2) g. The result was shown in mg/g of wet weight.

Mathematical data processing was performed using one-way analysis of variance (ANOVA) with the Tukey's a posterior analysis under Levene's test. The relationship between monthly average meteo-indicators and pigment concentrations was determined by multiple regression analysis, followed by the calculation of Durbin-Watson statistics and serial correlation in the program Statistica 10.0 (StatSoft Inc. 2011).

Results

At the beginning of the experiment, the observation of planting conditions in the city were conducted. Taking into account the lack of sensitivity of the method of visual estimation, the general vital status of the even-aged trees of each species was determined on m.s. 1 and m.s. 2. The following groups were identified among the plant species under study: the first group (8 points) – the stable species *Robinia pseudoacacia* L., *Populus simonii* Carriér; the second group (6-7 points) medium-stable species *Acer platanoides* L., *Populus ×canadensis* Moench, *Syringa vulgaris* L., the third group (4-5 points) nonsufficient stable - *Acer pseudoplatanus* L., *Acer negundo* L., *Tilia cordata* Mill.

In order to determine the physiological aspects of the plant's vitality due to the different hydrothermal conditions of the vegetation period of two years of research, we analyzed the pigment content in the leaves of the investigated species in the control, without influence of urban factors. High level of chlorophyls sum was established in the conditions of July and September 2012 which were prosperous to the plants, mainly owing to chlorophyll *a (*Fig. 2a*)*. This reaction is principally shown in the species of the third group - *Acer pseudoplatanus* L., *Acer negundo* L., *Syringa vulgaris* L., as well as in the trees of the second group - *Acer platanoides* L. Amount of rainfall in these months exceeds the limit by 74 % in July and 189 % in August of 2012. It should be noted that the concentration of green pigments of these species under the conditions of severe drought in September decreases extremely, except for *Syringa vulgaris* L., that characterizes with increasing of *chl a* and *chl b* amount. It is evidenced about the adaptation potential of *Syringa vulgaris*. The high chlorophyll concentration in more stable to the urban conditions species of the first and second groups were estimated on the start of vegetation in the May-June under the lack of humidifying.

It is found out the dynamic of chlorophyll concentration of two species *Populus simonii* and *Acer pseudoplatanus,* that represent the groups with the most and least stable species, under the influence of stress hydrothermal conditions in the growing season 2013 (Fig.2b).

As a result of multiple regression analysis the rainfall and air humidity are determined as the main factors influencing the content of green pigments in the leaves of species from the second and third groups in the control conditions (Table 1a). However *chl a*+*b* of species where the maximum content of green pigments is observed in drought periods of the year depends on the air temperature. For example, for *Populus simonii* (stable species) correlation with air temperature is established in the same way as for the medium-stable species *Syringa vulgaris* (R^2=0.81).

Sum of chlorophylls for the leaves of *Syringa vulgaris* in 2012 is described by linear equation:

$$y = 13.1192+0.0356 \cdot x_1-0,4561 \cdot x_2,$$

where y – sum of chlorophylls (mg/g), x_1 – amount of rainfall (mm), x_2 – temperature (ºC).

Content of carotenoids in all investigated species in the control increases from May to October, however, the rate of its growth varies (Fig. 3). The most significant difference between carotenoids content at the beginning and the end of vegetation is established for *Acer platanoides* (4 times in October compared to May figure). Increase in the content of yellow pigments at the end of vegetation relates to the preparation of plants for winter and destruction of green pigments. The negative significant influence of temperature was revealed for this species (Table 3).

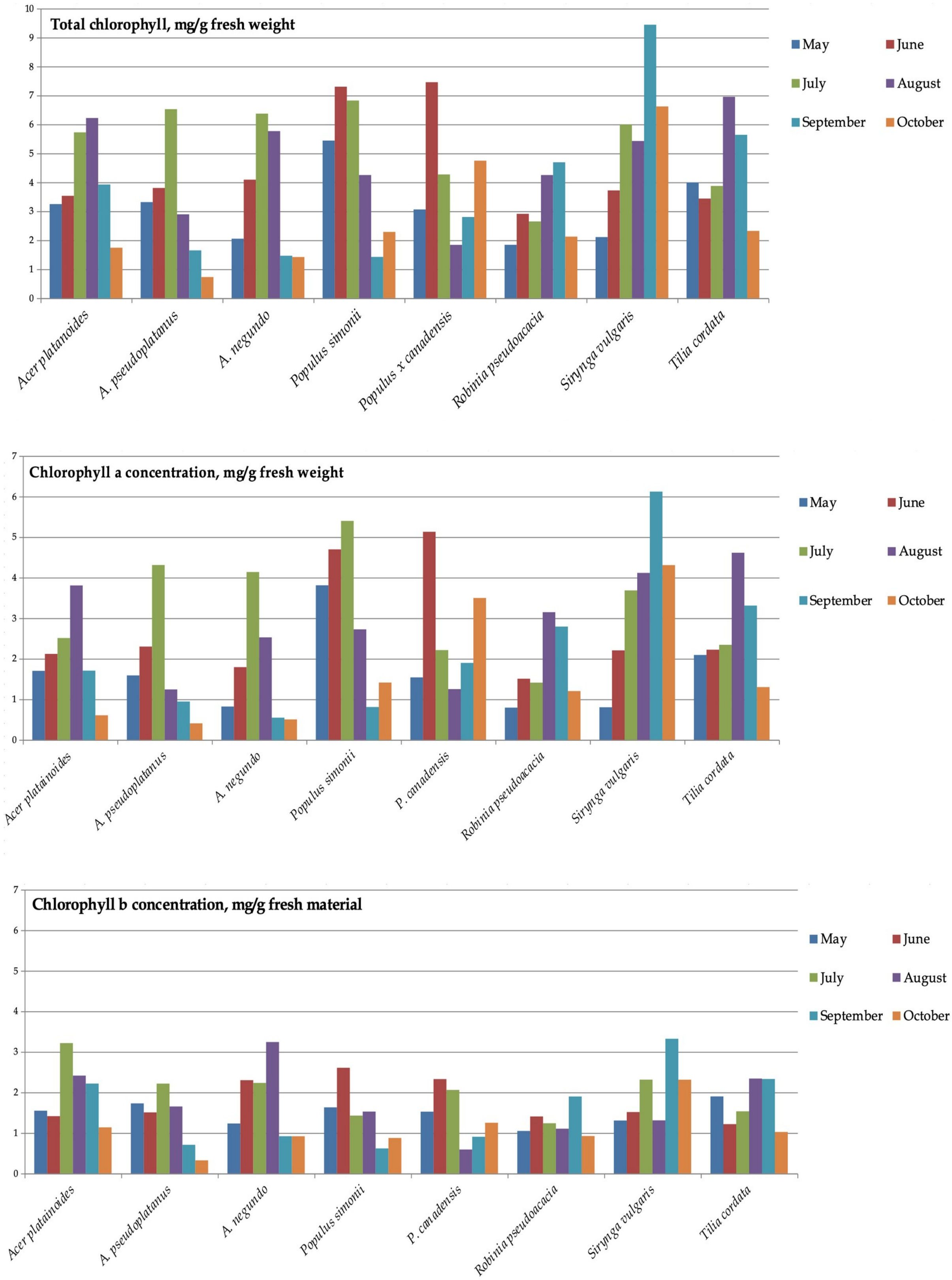

Fig. 2a. The chlorophyll concentration (total, *chl a* and *chl b*) in leaves of the investigated species from May to October at monitoring site 3 (Tonenke) – 2012.

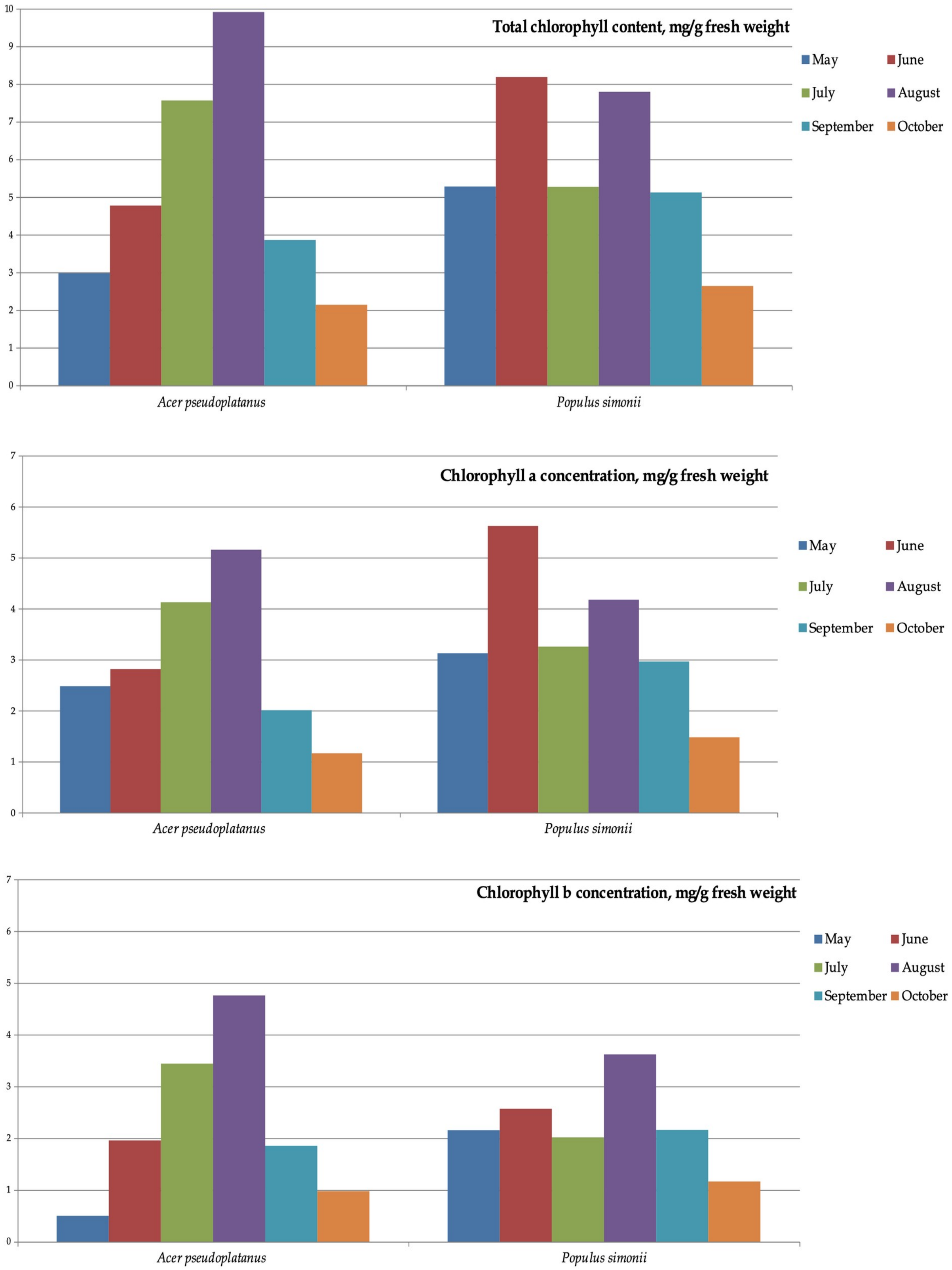

Fig. 2b. The chlorophyll concentration (total, *chl a* and *chl b*) in leaves of the investigated species from May to October at monitoring site 3 (Tonenke) – 2013.

Populus simonii and *Populus* × *canadensis* are characterized by the absence of the autumn leaf color at the end of vegetation, unlike the other tree species. In connection with this the content of carotenoids in the leaves of this species in October remains unchanged compared to May (Fig. 3). It should be noted that in June during the drought the content of carotenoids in *P. simonii* increases, indicating the protective role of carotenoids.

For stable species *Populus simonii* and nonsufficient stable species *Acer pseudoplatanus* (Fig.2b) it is found that the dynamics of chlorophyll content differs from year to year, but air temperature remains the main factor (Table 2).

The tendency of the pigment content changes during the growing season at m.s. 1 and m.s. 2 corresponds to the dynamics in control (m.s. 3), so the results are presented for one month of each season (Table 4). In summer and autumn, June and October are selected as the drought periods with unfavorable conditions for the growth and development of trees (Table 4).

Analysis of obtained results (Table 4) shows that reduction of chlorophyll content is observed in the leaves of species under study in street and park plantations in the conditions of contamination and urbanization compared to control against the same background of the hydrothermal conditions. For example, in June the sum of chlorophylls in *Tilia cordata* decreases by 39.2 % at m.s. 1 and by 25.8% at m.s. 2, indicating the physiological changes which occur in the plant body under action of pollutants.

More intensive reduction of the sum of chlorophylls in the leaves of species under study is recorded at m.s. 1 compared to m.s. 2 and control. The significant difference was recorded in May, under favorable weather conditions, in young leaves, which are more sensitive to airborne pollutants, of all species except *Syringa vulgaris*. For example, in the leaves of *Acer negundo* the chlorophyll content decreased by 51.7 % at m.s. 1 and by 31.7 % at m.s. 2 compared to control. The lowest sensitivity to pollutants was found for the leaves of *Robinia pseudoacacia* and *Syringa vulgaris.* Their sum of chlorophylls has grown by 54.9 % and 18.5 % at m.s. 1 respectively.

During the first draught in June *A. pseudoplatanus* (decrease in sum of chlorophylls by 57.9% and 28.7 % at m.s.1 and m.s.2 respectively), *Populus simonii* (62.5 % and 46.4 % m.s. 1 and m.s. 2), *P.* x *canadensis* (25.2 % and 72.4 % at m.s. 1 and m.s. 2) are more sensitive to contamination. *Acer platanoides, A. negundo, Syringa vulgaris* L. and *Tilia cordata* are less sensitive to contamination; chlorophyll content in them decreases from 22.0 % to 39.2 % depending on species at m.s. 1 compared to control. *Robinia pseudoacacia* is the most resistant to contamination during drought in June; chlorophyll content increases by 15 % at m.s. 1 and m.s. 2 respectively.

During the drought in October it is found at m.s. 1 that contamination has less significant impact on the condition of photosynthetic apparatus in all species, due to lower sensitivity of old leaves to adverse abiotic and anthropogenic factors of the environment. High endurance against contamination and prolonged drought was demonstrated by *A. pseudoplatanus* L., *Populus simonii, P.* x *canadensis, Robinia pseudoacacia* and *Syringa vulgaris.*

According to the results of studies it is established that at m.s. 1 and m.s. 2 the carotenoid content in the leaves of model specimens increases compared to the control, but the degree of increase depends on plant resistance, as can be seen from the dynamics of carotenoid content in June (Table 5).

The content of carotenoids in stable species (*P. simonii*, *P.* × *canadensis*, *Robinia pseudoacacia*) features almost no difference on Kyivskyi avenue (m.s. 1) and in the Recreation and Entertainment Park (m.s. 2) during vegetation. The established pattern indicates high resistance of these woody plants to conditions of the urban environment. Concentration of yellow pigments in *Acer pseudoplatanus* and *A. negundo*, growing in the park, increases by 30–35 % compared to m.s. 3, showing the sufficient level of adaptation of these species to conditions of the urban environment. Considerable increase in carotenoids in street and park plantations is recorded in *Acer platanoides*, *Syringa vulgaris* and *Tilia cordata* which are less stable.

The ratio of sum of chlorophylls to carotenoids (a+b/car.), as a rule, is constant in the normal conditions and promptly responds to changes in the environment, so it is used as an indicator of plants' adaptation to extreme conditions (Petrova et al., 2014). In order to understand the simultaneous action of abiotic stress – drought and anthropogenic pressure, the ratio a+b/car. was calculated for June 2012.

In most species a+b/car. varied from 4.86 (*Acer platanoides*, m.s. 1) to 9.05 (*Tilia cordata*, m.s. 3) (Fig.4).

Table 1. Stepwise regression analysis for sum of chlorophylls of woody plants in the vegetation period of 2012 (Tonenke, m.s. 3). Negatively correlated variables are highlighted in bold. Statistical significance, p-value: < 0,05 = *; < 0,001 = **; < 0.0001***.

Species	Step 1	Step 2	Step 3
Populus × canadensis	Falls 0.09***	Falls Temp 0.69***	-
Populus simonii	Temp 0.54***	Temp Falls 0.06***	Temp Falls Hum 0.14*
Tilia cordata	Falls 0,04***	Falls Hum 0.05**	
Robinia pseudoacacia	Falls 0.008*	Falls Hum 0.05**	-
Acer negundo	-	Hum 0.11*	
Acer platanoides	Falls 0.02***	-	-
Acer pseudoplatanus	Hum 0.30***	Hum Falls 0.03***	Hum Falls Temp 0.14**
Syringa vulgaris	Temp 0.46**	Temp Falls0.04*	

Table 2. Stepwise regression analysis for sum of chlorophylls of woody plants in the vegetation period of 2013 (Tonenke, m.s. 3). Negatively correlated variables are highlighted in bold. Statistical significance, p-value: < 0.05 = *; < 0.001 = **; < 0.0001***.

Species	Step 1	Step 2	Step 3
Acer pseudoplatanus	Temp 0.22***	**-**	**-**
Populus simonii	**Temp 0.66*****	**-**	**-**

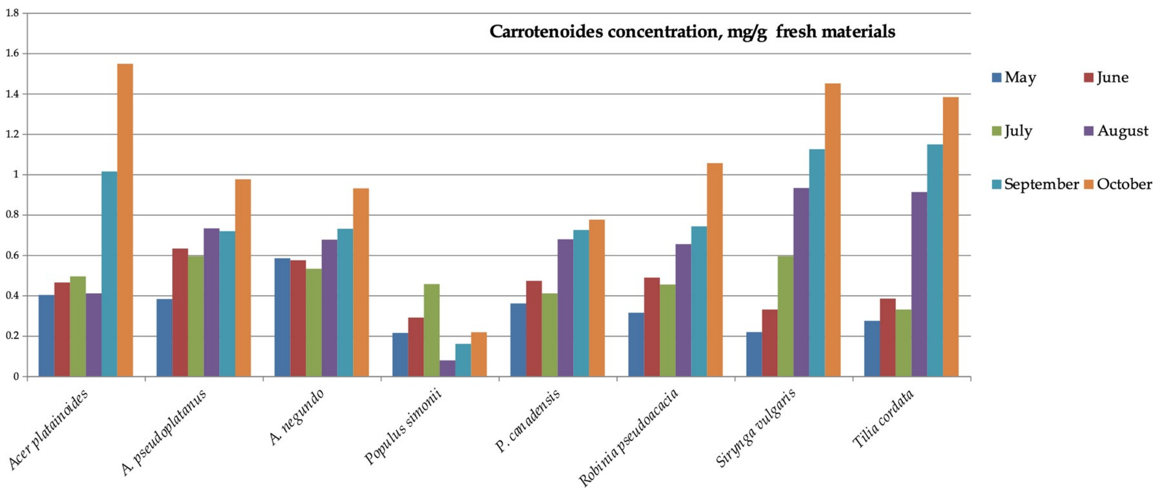

Fig. 3. The carotenoids concentration in leaves of the investigated species from May to October at monitoring site 3 (Tonenke) in 2012.

Table 3. Stepwise regression analysis for carotenoids concentration of woody plants in the vegetation period of 2012 on the control site. Negatively correlated variables are highlighted in bold. Statistical significance, p-value: < 0.05 = *; < 0.001 = **; <0.0001= ***.

Species	Step 1	Step 2	Step 3
P. × canadensis	Hum 0.02***	HumFalls 0.005***	HumFallsTemp 0.02**
P. simonii	Hum 0.02***	HumFalls 0.004***	-
Tilia cordata	Hum 0.04***	HumFalls 0.01***	HumFallsTemp 0.09***
Robinia pseudoacacia	Hum 0.02*	HumFalls 0.006***	HumFallsTemp 0.05***
Acer negundo	Temp 0.03***	TempFalls 0.003***	TempFallsHum 0.01***
A. platanoides	Temp 0.12***	TempFalls 0.004**	
A. pseudoplatanus	Hum 0.02*	HumFalls 0.004**	HumFallsTemp 0.03*
Syringa vulgaris	Temp 0.12***	TempFalls 0.01***	-

Table 4. Sum of chlorophylls of the species leaves at experimental sites during the vegetation period. Statistical significance: p-value: < 0,05 = *; < 0,001 = **; <0.0001= *** compared to control.

Species	May			June			October		
	m.s. 1	m.s. 2	m.s. 3	m.s. 1	m.s. 2	m.s. 3	m.s. 1	m.s. 2	m.s. 3
Acer platanoides	1.43 ±0.05***	1.32 ±0.04***	3.25 ±0.05	2.72 ±0.02**	3.14 ±0.05	3.53 ±0.02	1.13 ±0.06	1.15 ±0.01	1.74 ±0.01
A. pseudoplatanus	1.49 ±0.11***	2.48 ±0.25***	3.32 ±0.05	1.60 ±0.03***	2.71 ±0.07**	3.80 ±0.03	0.72 ±0.08	1.01 ±0.01	0.73 ±0.02
A. negundo	0.99 ±0.11***	1.40 ±0.07**	2.05 ±0.05	3.19 ±0.02	3.67 ±0.11	4.09 ±0.01	0.84 ±0.03	0.27 ±0.01	1.42 ±0.01
Populus simonii	1.44 ±0.08***	2.34 ±0.03***	5.44 ±0.04	2.77 ±0.05***	3.91 ±0.12***	7.30 ±0.02	1.43 ±0.06	0.81 ±0.01**	2.29 ±0.02
P. x *canadensis*	0.99 ±0.06***	1.93 ±0.06***	3.06 ±0.03	2.56 ±0.03***	6.36 ±0.05	7.46 ±0.04	3.55 ±0.02	4.31 ±0.01	4.75 ±0.02
Robinia pseudoacacia	2.85 ±0.07**	2.43 ±0.05**	1.84 ±0.02	3.35 ±0.03	3.37 ±0.02	2.91 ±0.01	1.37 ±0.03	1.64 ±0.02	2.13 ±0.02
Syringa vulgaris	2.50 ±0.06	2.85 ±0.09	2.11 ±0.02	2.57 ±0.03**	3.12 ±0.07	3.72 ±0.01	4.79 ±0.03	4.71 ±0.02	6.62 ±0.02
Tilia cordata	1.66 ±0.05***	1.95 ±0.04***	3.99 ±0.03***	2.09 ±0.04**	2.55 ±0.04*	3.44 ±0.03	1.25 ±0.03*	1.15 ±0.02	2.32 ±0.03

Table 5. Carotenoids content in some months of 2012 at experimental sites. Statistical significance: p-value: < 0,05 = *; < 0,001 = **; <0.0001= *** compared to control.

Species	May			June			October		
	m.s. 1	m.s. 2	m.s. 3	m.s. 1	m.s. 2	m.s. 3	m.s. 1	m.s. 2	m.s. 3
Acer platanoides	0.65 ±0.01***	0.53 ±0.02**	0.40 ±0.01	0.56 ±0.02	0.51 ±0.01	0.46 ±0.01	2.70 ±0.01***	2.13 ±0.01**	1.55 ±0.01
A. pseudoplatanus	0.55 ±0.02***	0.43 ±0.01	0.38 ±0.01	0.73 ±0.01**	0.68 ±0.01	0.63 ±0.01	1.45 ±0.01***	1.15 ±0.01	0.98 ±0.02
A. negundo	0.75 ±0.02***	0.62 ±0.02**	0.58 ±0.01	0.75 ±0.02***	0.66** ±0.02	0.57 ±0.01	1.23 ±0.02**	1.01 ±0.01	0.93 ±0.02
Populus simonii	0.31 ±0.01	0.27 ±0.01	0.21 ±0.01	0.38 ±0.01***	0.33 ±0.01	0.29 ±0.01	0.31 ±0.01	0.27 ±0.01	0.22 ±0.01
P. x *canadensis*	0.56 ±0.02***	0.49 ±0.03	0.36 ±0.01	0.60 ±0.01***	0.51**= ±0.01	0.47 ±0.01	0.95 ±0.01*	0.81 ±0.01	0.78 ±0.01
Robinia pseudoacacia	0.46 ±0.02***	0.39 ±0.01	0.31 ±0.01	0.61 ±0.02***	0.52* ±0.02	0.49 ±0.01	1.48 ±0.02**	1.31 ±0.02	1.06 ±0.03
Syringa vulgaris	0.33 ±0.01***	0.29 ±0.01	0.22 ±0.01	0.42 ±0.01***	0.39 ±0.01	0.33 ±0.01	2.23 ±0.01***	1.64 ±0.02	1.45 ±0.01
Tilia cordata	0.37 ±0.01**	0.33 ±0.02	0.27 ±0.01	0.47 ±0.01***	0.43 ±0.01	0.38 ±0.01	1.92 ±0.01**	1.71 ±0.02	1.38 ±0.02

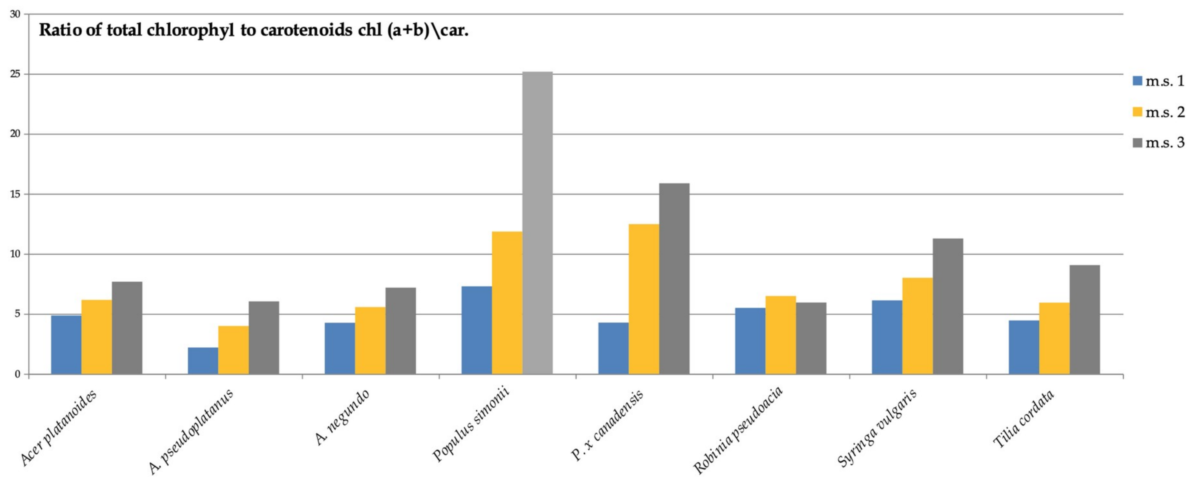

Fig. 4. The ratio of total chlorophylls to carotenoids in June, 2012 during the drought at monitoring sites.

However, this indicator in representatives of *Populus* and *Syringa vulgaris* genera exceeds the general range. For example, for *Populus simonii* and *Populus* × *canadensis* the maximum level of the ratio in the control (25.17 and 15.87 respectively) is established, and for *Syringa vulgaris* it makes 11.27, because of high chlorophyll concentration and low content of carotenoids. The tendency to growth of the concentration of green pigments and reduction of yellow ones in the control is maintained for the other species, except *Robinia pseudoacacia.* The highest ratio *chl a+b/car* is found in this species for the plants in park plantations, exceeding this indicator at m.s. 1 and m.s. 3 by 1.1 times only.

Therefore, contamination in the park plantations affects the plants which fact is confirmed by changes in the composition of the pigment apparatus of leaves, but in street plantations in the conditions of heavy traffic the reduction of chlorophyll content and increase of carotenoids in the investigated species is more significant. In stable species of trees (*Populus simonii, P.* × *canadensis, Robinia pseudoacacia*) these changes are less critical compared to medium-stable and nonsufficient stable species (*Acer pseudoplatanus, A. negundo, A. platanoides, Syringa vulgaris* and *Tilia cordata*).

Discussion

As a result of our study it is found that concentration of chlorophylls and carotenoids in woody plants varies depending on the meteorological factors during the season and on the level of contamination of urban areas. The growth of chlorophyll content in the leaves of trees under study from May to September is established, which is consistent with the literature sources (Petrova et al., 2017; Iusypiva & Vegerich, 2014). It is determined that the main factor influencing the chlorophyll formation is the air temperature. Stable and medium-stable species *Robinia pseudoacacia, Populus simonii, Acer platanoides, Populus* × *canadensis, Tilia cordata* have the largest chlorophyll amount in drought periods. As it is stated by Ballester et al. (2017), fruit species of trees also demonstrate high dependence on the formation of green pigments on the air temperature. During experiments for *R. pseudoacia*, *Tilia cordata*, and *A. platanoides* direct dependence on rainfall is established which is consistent with the results of Iusypiva & Vegerich (2014) for Dnipro City in 2012 for *R. pseudoacia*, in the leaves of which the maximum sum of chlorophylls was recorded in the month with the highest amount of rainfalls as well. The established pattern indicates less adaptive capacity of the representatives of *Robinia, Tilia* and *Acer* genera to the conditions of hydrothermal stress.

Under action of drought in the leaves of representatives of *Acer* genus (Swozcerna et al., 2010) the chlorophyll content increases, which agrees with the results of our experiments for *A. pseudoplatanus*, when at high temperatures and low rainfall in August 2013 the maximum amount of chlorophylls in the leaves of this species was recorded. This pattern indicates high adaptive capacity of sycamore maple in the conditions of South-East of Ukraine. Another species *Populus simonii* is defined by a high concentration of pigments under stress conditions at the start of vegetation period, a more stable level of chlorophyll content during the growing season. It should be noted that under the more prosperous conditions in June maximum is being reached by *chl a* fraction, under the stress conditions in August - due to the sharp increase in the *chl b* fraction, as well as it is found out a higher relative content of *chl b* at the end of the growing season. The obtained results show that the various in stability species in urban environment differ in the ratio of *chl a* and *chl b* under the action of hydrothermal factors of different tensions, that can be one of the part of the demonstration of species adaptive strategy.

Increase in sum of chlorophylls in *A. platanoides* and *A. negundo* in July and August 2012, when the amount of rainfall was higher in 74 and 190 % to the normal value accordingly, occurred due to increase in the proportion of chlorophyll *b*, which plays the protective role in addition to its main function. Chlorophyll *b* absorbs some of the rays, expanding the range of photoactivity which is particularly important in the conditions of considerable cloudiness in rainy weather. Chlorophyll *a* is more resistant to adverse environmental factors compared to chlorophyll *b* (Conzales-Dugo, 2017; Bessonova et al., 2006). Increase in the sum of chlorophylls during drought in *Acer pseudoplatanus, Populus* x *canadensis, P. simonii, Robinia pseudoacacia, Syringa vulgaris* at the expense of chlorophyll *a* indicates the normal development of the photosynthetic apparatus of these species and their high adaptive reactions under conditions of hydrothermal stress.

The linear equations of total chlorophyll and meteorological factors (falls and temperature) for both years were constructed for two investigates species:

Acer pseudoplatanus $y = -5.1278-0.0258 \cdot x_1+0.4658 \cdot x_2$ with $R^2 = 0.98$, in 2012 and $y = -6.8888-0.0529 \cdot x_1+0.6888 \cdot x_2$ with $R^2 = 0.81$ in 2013;

Populus simonii $y = -6.8888-0.0529 \cdot x_1+0.6888 \cdot x_2$ with $R^2 = 0.60$, in 2012 and $y = -1.2985+0.058 \cdot x_1-0.3181 \cdot x_2$ with $R^2 = 0.77$, in 2013, where y – sum of chlorophylls (mg/g), x_1 – amount of rainfall (mm), x_2 – temperature (ºC).

As can be seen from the linear equations, general tendency of pigments amount for change in the leaves despite the different weather conditions remains unchanged. Linear equations obtained for *Acer pseudoplatanus* confirm the inverse relationship between air temperature, rainfall, and sum of chlorophylls during the growing season in 2012.

Maximum chlorophyll content in the leaves of *Acer pseudoplatanus* falls on hot months, both in conditions of excessive humidity (July, 2012) and during the drought period (August, 2013). For *Populus simonii* the highest chlorophyll content is recorded in June, at high temperatures but varying amount of rainfall. The established pattern indicates high adaptive capacity of *A. pseudoplatanus* and *Populus simonii* during the drought.

Carotenoids fulfill the protective function by preventing the destruction of chlorophyll molecules in the light in the process of photo-oxidation. Photo-protective function lies in the fact that yellow pigments protect the reaction center from massive energy fluxes at high light intensities (Britton et al., 2008, Bessonova, 2006). As shown by the results of our study, in summer months the content of carotenoids in species under study increases. The highest indicators of carotenoids are found in autumn during the plants' preparation for winter.

During vegetation on the experimental sites (m.s. 1 and m.s. 2) the content of green pigments increases in late spring and during summer with the further decrease in concentration in autumn, which corresponds to the dynamics of chlorophyll change in the control. According to Zayika & Bondarenko (2018), the content of chlorophyll is reduced in the leaves of deciduous species in the area of the western forest-steppe of Ukraine in autumn which is agreed with our results for the southeastern steppe.

Sum of chlorophylls in most species at the monitoring sites is composed by chlorophyll *a*, except for *A. platanoides* and *A. negundo*, as in control. Formation of chlorophyll *b* molecules is reduced because of inhibition of enzymes of its synthesis under action of xenobiotics (Petrova et al., 2017; Bessonova et al., 2015).

Covering of the question regarding changes in carotenoids in the leaves of trees of street plantations in the literature is ambiguous. For example, Petrova et al., 2017, for *Acer heldreichii* Boiss. & Heldr. and *Tilia tomentosa* Moench point to the decrease in carotenoids at the contaminated site, however for *Fraxinus excelsior* – to growth of their content in the conditions of impact of car exhausts. Reduced content of carotenoids under impact of car exhausts is also recorded by Joshi & Swami (2009). Increase in concentration of the yellow pigments under action of car exhausts is established in the studies of Sillanpää et al. (2008) for *Betula pendula* Roth, which may suggest different adaptive capacity of trees and varying levels of contamination. Korshikov & Vinogradova (2013) note the increase of carotenoids in damaged leaves of *Acer pseudoplatanus* and *Acer platanoides* under action of pollutants from the work of internal combustion engines in Donetsk.

According to results of our study, the functional state of trees in street and park plantations is worse compared to control, which is confirmed by the decrease in chlorophyll content and growth of carotenoids. Carotenoid content at m.s. 2 increases to 30 %, and at m.s. 1 – to 50 %, indicating the adaptive capacity of plants, since carotenoids possess high antioxidant power. The total number of chlorophylls is reduced by 20 to 30% in the trees of park plantations, and by 40–50% in the street plantations, compared to the clean site.

It is to be noted that the representatives of the first group (stable species), such as *Robinia pseudoacacia*, shows the exceedence of sum of chlorophyls during the drought periode at m.s. 1 and m.s. 2. At the same time the species of the second group (medium-stable species), for example, *Syringa vulgaris* decreases level of chlorophyls content under the unfavorable urban and hydrothermal conditions, as well as, Tilia cordata from the third (nonsufficient stable) groups decreases amount of chlorophylls and increased carotenoid content. The obtained predicted pain evidences the adaptive strategies of the studied species under anthropogenic and hydrothermal stress.

Therefore, it is found that contamination in the park plantations affects the plants which fact is confirmed by changes in the composition of the pigment apparatus of leaves, but in street plantations the reduction of chlorophyll content and increase of carotenoids in the investigated species is more significant. In stable tree species (*Populus simonii, P.* × *canadensis, Robinia pseudoacacia*) these changes are less critical than in less stable species (*Acer pseudoplatanus, A. negundo, A. platanoides, Syringa vulgaris* and *Tilia cordata*).

Conclusion

As a result of the study, the functional state of trees in street and parks plantations was found to be weakened, which indicates a decrease in the content of green pigments and an increase in the concentration of carotenoids in the area of automobile vehicle exhaust. The impact of hydrothermal conditions and factors of urban environment determines the corresponding changes in the concentration of photosynthetic pigments in woody plants differentiated by vitality. It is established among meteorological factors air temperature as the main factor. Changes in the concentration of green pigments in the leaves of species under study, depending on the temperature and rainfall, are described by linear equations, which is important for predicting the growth and development of plants during green building on urban territories in the conditions of the steppe zone.

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