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FEATURES OF OPERATION OF THE PLANT PIGMENT SYSTEM IN A MAN-MADE ENVIRONMENT

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Abstract

The paper shows the dynamics of photosynthetic pigment content in the leaves of native and introduced species of woody plants within the urban environment conditions. Fine-leaved linden and pendent birch growing in the plantations of sanitary protection zones of industrial enterprises and at main planting the content of chlorophyll a and b is reduced during the growing season in comparison with the plantation plants of conditional control zones, but at the same time the content of carotenoids with antioxidant properties and a protective function is increased. Balsam poplar in main plantations has an increased content of chlorophylls and carotenoids in June, but then their decrease takes place. The representatives of maple genus had a significant decrease of chlorophyll a content in leaves throughout the observation period in the city plantations. Chlorophyll b content increase was observed in leaves of the aboriginal species - Norway maple - in main plantations at the beginning of active vegetation period in 2015, and among the plantations of sanitary protection zones and in industrial enterprises and in plantations in July 2014, compared with the plantings of conditional control zones, which indicate its participation in adaptive reactions. Ash-leaved maple - an introduced species - is characterized by b chlorophyll content reduction during an active vegetation period, compared with the indicators of conditional control zone during the same interval. Besides, the leaves of maple species demonstrate carotenoid content increase in June.

Keywords: Woody plants, Pigment system, Man-made stress, Resistant types.

Introduction

The environmental pollution by vehicle emissions and large industrial enterprises influence various functions of a plant organism, including the activities of the photosynthetic apparatus. On the other hand, the assimilation activity of

plants is the primary metabolic process, the efficiency of which determines the growth and reproductive processes. Of course, the photosynthetic structures and processes are the indicators of a plant organism general state [Golovko, 2008; Bukharina, 2014; Cheeseman, 2007; Galves-Valdivieso, 2010; Gill, 2010].

The studies carried out with different types of plants show a specific reaction of study objects on the effects of different environmental factors, both abiotic and anthropogenic ones. In this regard, the issue of dynamics study in respect of chlorophyll a and b, carotenoid content in the leaves of woody plants depending on the degree of anthropogenic impact remains a relevant one [John, 2008; Delia-Gabriela, 2012].

Based on this fact, we set the goal to study the features of content dynamics in the leaves of photosynthetic pigments during the active vegetation period of several species of woody plants growing in the plantations of different environmental categories in a large industrial center of the city of Naberezhnye Chelny (Republic of Tatarstan). The vegetation period of 2014 and 2015 was characterized by high air temperature. The exceeding of the average long-term data ranged within +7 ... + 11 $^{\circ}$C. The amount of precipitation was below standard.

A comprehensive air pollution index (API) shows a very high pollution (API = 15.3) and an exceeded level of maximum permissible concentration (MPC) for benz(a)pyrene, formaldehyde, phenol, carbon and nitrogen oxides. The sanitary protection zone (SPZ) of industrial enterprises has the average annual excess of the MPC concerning the following materials: carbon oxides - 2 times, nitrogen oxides - 3 times, sulfur dioxide - 1.2 times, formaldehyde - 5 times, phenol - 1.7 times, benz(a)pyrene - 1.9 times. The area of main plantations has the following average annual excess of MPC in the following materials: carbon oxides - 3.4 times, formaldehyde - 3.8 times, phenol - 1.4 times, benz(a)pyrene - 1.5 times [State.., 2014].

Materials and methods

The object of the study was woody plants: indigenous species - Norway maple (Acer platanoides L.), small-leaved lime (Tilia cordata Mill.) and drooping birch (Betula pendula Roth.); introduced species - ash-leaved maple (Acer negundo L.) and balsam poplar (Populus balsamifera L.).

The studied species grew in the city as the part of plants of different environmental categories: main plantations (MP) (major motorways "Auto 1" and the prospect Mira) and the sanitary protection zone (SPZ) of industrial enterprises - OJSC "KamAZ", forge and foundry plants, which are major polluters of the city. Chelninsky forestry (forest-steppe zone, the total area of forestry makes 9539 hectares) was selected as conditional control zones (CCT) for drooping birch, small-leaved lime and ash-leaved maple.

The introduced species - ash-leaved maple and balsam poplar - were examined on the territory of the city park "Grenada" [Atlas.., 2005].

Trial plots were laid in a regular way (5 pcs. in each area, the size of which makes 0.25 ha at least). The selection was performed in a test site (10 plants of each species) and the numbering of registered woody plants. The registered species had a good living condition and middle-aged generative ontogenetic state (g2). The selection of soil samples (mixed sample composed of individual samples taken by the method of envelope) was performed in the areas of test plots development. In order to perform laboratory physiological and biochemical analyzes of the registered plants the samples of distal vegetative annual shoots and median (assimilating) leaves were collected, which were taken from the middle and lower part (except for the lower branches) of southern exposure crown with the secateur fixed to the pole. Each registered species was tested in triplicate.

The content of chlorophyll a, b and carotenoids in the leaves of woody plants was determined under laboratory conditions by spectrophotometry method (Spectrophotometer PE-5400 VI, Russia) in acetone extracts (the absorption makes 662, 644 and 440.5 nm, respectively). The concentration of pigments was calculated according to Hill-Wettstein equations. During the performance of dispersed analysis the study results were averaged according to plantations of similar environmental categories [Mokronosov, 1978].

The mathematical processing of materials was carried out using the statistical package "Statistica 5.5". In order to interpret the results obtained the methods of descriptive statistics and multifactor dispersed analysis (according to cross-hierarchical scheme were used at the subsequent assessment of differences by multiple comparison method LSD-test).

Results and discussion

The performed agrochemical analysis showed that the soils in the plantations of conditional control zones have a slightly alkaline reaction, the average content of organic matter, the content of mobile phosphorus was increased or a very high one, the content of exchangeable potassium content was high or a very high one. There was a high content of nitrogen nitrate forms and a low content of nitrogen ammonium forms.

The soils sanitary protection zones at industrial enterprises were characterized by a weakly acidic and weakly alkaline reaction, an average or a high organic matter content, about 247-300 mg/kg of nitrate nitrogen forms and 6.1-14.9 mg/kg of ammonium nitrogen forms. The main plantations of soils had the following characteristics: exchange acidity 7.4-7.7 (pH_{H2O} = 8.4-8.6), characterizing the slightly alkaline reaction of soils; low content of organic matter;

low and moderate content of ammonia nitrogen and mobile phosphorus; an average content of nitrate nitrogen; high and very high content of exchangeable potassium.

The statistical processing of the obtained results concerning the research of photosynthetic pigment content was carried out using the methods of cluster and multifactor dispersion analysis.

Cluster analysis was applied in order to identify the groups with similar indicators of content and photosynthetic pigment dynamics. It is allowed to distinguish two major clusters: the first one combined all kinds in all areas concerning carotenoid content, the second cluster is characterized by a and b chlorophyll content. The results of cluster analysis conducted separately for each studied species of woody plants were similar ones. This indicates the difference of carotenoids a and b chlorophyll performed functions among the plants in urban environment conditions.

In order to assess the urban environment factor influence on the content of photosynthetic pigments in the leaves of woody plants performed the dispersion multifactor analysis was performed. It showed a significant impact of specific features (the significance level is $P<10^{-5}$), the set of conditions concerning cultivation site ($P<10^{-5}$), vegetation periods ($P<5.10$), as well as the interaction of these factors ($P = 4.38 \cdot 10^{-5}$) on the chlorophyll a content in the leaves of woody plants (Table).

Table - The dynamics of chlorophyll a and b, carotenoid content in the leaves of woody plants growing in the plantations of Naberezhnye Chelny city, mg/g of dry matter

Woody plant type	Pigment	Plantations								
		Conditional control zones			Sanitary protection zones of industrial enterprises			Main lines		
		June	July	August	June	July	August	June	July	August
2014										
Tilia cordata Mill.	chlorophyll *a* (*LSD_{05} = 0.01)	1.03	2.63	1.88	1.17	2.45	1.58	1.21	2.39	1.39
	chlorophyll *b* (LSD_{05} = 0.02)	1.56	2.86	2.10	1.73	2.91	2.70	1.60	2.89	2.00
	carotenoids	0.86	1.76	0.66	1.14	1.87	0.66	1.10	1.77	0.64

	(LSD_{05} = 0.01)									
Populus balsamifera L.	chlorophyll *a*	1.32	2.17	1.71	1.22	1.91	1.11	1.28	1.84	1.11
	chlorophyll *b*	1.29	2.16	1.90	1.18	1.85	1.03	1.18	1.85	1.03
	carotenoids	0.90	1.81	1.22	1.27	1.78	1.04	1.03	1.80	1.01
Betula pendula Roth.	chlorophyll *a*	1.45	2.16	2.00	1.36	1.87	1.66	1.47	2.08	1.84
	chlorophyll *b*	1.62	2.81	2.49	1.59	2.64	2.39	1.63	2.80	2.39
	carotenoids	0.90	1.89	0.92	1.21	1.68	0.98	1.21	1.57	0.86
Acer platanoides L.	chlorophyll *a*	1.95	2.73	2.44	1.89	2.28	1.68	1.83	2.13	1.58
	chlorophyll *b*	2.65	3.39	3.64	2.44	3.69	3.01	2.41	3.51	2.01
	carotenoids	1.08	1.91	1.25	1.19	1.92	1.08	1.25	1.80	1.10
Acer negundo L.	chlorophyll *a*	1.21	2.40	1.90	1.19	2.09	1.61	1.13	2.03	1.34
	chlorophyll *b*	2.79	3.32	2.55	2.49	3.19	1.89	2.59	3.07	1.82
	carotenoids	0.96	1.85	1.11	0.84	1.76	0.98	0.93	1.71	0.84
2015										
Tilia cordata Mill.	chlorophyll *a* (LSD_{05} = 0.03)	1.21	2.35	1.42	1.42	2.06	1.20	1.49	2.15	1.29
	chlorophyll *b* (LSD_{05} = 0.03)	1.44	2.63	1.89	1.64	2.67	1.79	1.69	2.73	1.78
	carotenoids (LSD_{05} = 0.03)	0.89	1.74	0.65	1.10	1.82	0.61	1.11	1.83	0.61
Populus balsamifera	chlorophyll *a*	1.19	1.94	1.51	1.19	1.79	1.10	1.27	1.76	1.31

L.	chlorophyll *b*	1.22	2.19	1.71	1.42	2.16	1.39	1.44	2.22	1.50
	carotenoids	0.92	1.81	1.13	1.13	1.72	1.01	1.01	1.74	0.90
Betula pendula Roth.	chlorophyll *a*	1.30	2.12	1.87	1.44	1.89	1.58	1.47	2.14	1.56
	chlorophyll *b*	1.45	2.43	1.93	1.47	2.23	1.80	1.64	2.48	1.71
	carotenoids	0.85	1.86	0.92	1.23	1.54	0.82	1.32	1.61	0.78
Acer platanoides L.	chlorophyll *a*	1.85	2.49	2.22	1.68	2.17	1.92	1.69	2.16	1.75
	chlorophyll *b*	2.17	3.14	2.97	2.11	2.87	2.70	2.24	2.67	2.56
	carotenoids	1.05	1.89	1.23	1.16	1.81	1.04	1.24	1.78	1.03
Acer negundo L.	chlorophyll *a*	1.19	2.20	1.72	1.07	1.91	1.49	1.10	1.87	1.27
	chlorophyll *b*	2.61	3.13	2.46	2.50	2.96	1.93	2.61	2.93	1.88
	carotenoids	0.97	1.75	1.09	0.87	1.68	1.01	0.91	1.60	0.91

Note. * LSD_{05} - lowest statistical difference, the level of significance $P<0.05$.

All studied species demonstrated a similar dynamics in chlorophyll a content: its increase in July compared with June and its decrease in August. At that chlorophyll a content among the majority of plant species is higher in August than in June. The maximum amount of this pigment in leaves was observed in July. At that certain differences among species were established due to the cultivation conditions in the plantations belonging to different environmental categories.

In 2014 and 2015 the representatives of maple genus, cultivated in the plantations of industrial zones and in main planting had the pigment content reduction in leaves and the inhibition of photosynthetic activity in comparison with the control park plants during the whole period of active vegetation. The chlorophyll a content in Norway maple of these plantations was lower, respectively, in comparison with control vegetation: in June - by 0.06-0.17 and 0.12-0.16, in July - by 0.45-0.32 and 0.60-0.33, in August - by 0.76-0.30 and 0.86-0.47 mg/g of dry matter. Maple ash in June - by 0.02-0.12 and 0.08-0.09; in July - by 0.31-0.29 and 0.37-0.33; in August - by 0.29-0.23 and 0.56-0.45 mg/g of dry matter (at LSD_{05} = 0.01). This indicates the high sensitivity of the pigment system to difficult environmental cultivation conditions among these plant species. Similar results in chlorophyll a content were marked among balsam

poplar, except for the beginning of active vegetation of plants in 2015 (June), when main plantations noted the excess of this pigment content in leaves compared with the plants in the plantations of conditional control zone. Later, during the vegetation period the plants in special plantations had lower rates of this pigment content in comparison with the park plantations.

During the study period the nature of chlorophyll a content change in small-leaved linden and drooping birch was a similar one. In June the main plantations and the plantations of industrial zones recorded a significantly higher content of pigment in leaves compared with CCZ. Later, chlorophyll a content in July and August did not exceed the indicators of conditional control zones.

Dispersion multifactor analysis of study results in 2014 and 2015 revealed a significant influence of species features ($P<10^{-5}$), the set of vegetation area conditions ($P<10^{-5}$), the vegetation periods ($P<10^{-5}$), as well as the interactions of these factors ($P = 1.64 \times 10^{-5}$) with chlorophyll b content in woody plant leaves.

All studied species had a similar dynamics in chlorophyll b content. There was its increase in July as compared with June and the decrease in August, with certain differences in species, due to the growing conditions in the plantations belonging to different environmental categories.

The maximum content of chlorophyll b is recorded among maple genus. In July 2014 Norway maple among the plants of main plantations and the plantations of sanitary protection zones at industrial enterprises were 0.12 and 0.30 higher, and there was the decrease by 0.21-0.24 and by 0.63-1.63 mg/g of dry matter in June and August, respectively, compared to the same indicator among CCZ plantations (3.39) at LSD_{05} = 0.02 mg/g of dry matter. At that the accumulation of chlorophyll b in the leaves of Norway maple was not similar: there was a gradual increase in pigment content at control plantations during the observation period took; CCZ plantations of industrial enterprises and main plantations demonstrate some increase in July (1.04 and 0.12, respectively, LSD_{05} = 0.02 mg/g of dry matter) and the subsequent decline in August (0.38 and 1.63 mg/g of dry matter, respectively), compared with conditional control zone plantations. In June 2015 the Norway maple demonstrated chlorophyll b content increase in leaves by 0.07, and then there was its decrease in July by 0.47 and in August by 0.41 mg/g of dry matter as compared with CCZ plantations and in CCZ plantations of industrial enterprises during the whole period of plant active vegetation. Ash-leaved maple showed the reduction of chlorophyll b content in the leaves during the vegetation period in urban spaces during two years, with the exception of indicators in June 2015 among the plants in main plantations, where its content had no reliable differences with CCZ and made 2.61 mg/g of dry matter. In 2014 the

drooping birch and balsam poplar had similar dynamics: in CCZ conditions of industrial enterprises and in main plantations chlorophyll b content in the leaves of woody plants was lower as compared to control plantations during the whole observation period. In 2015, drooping birch and balsam poplar recorded the increase of pigment content as compared with CCZ plantings, in June - by 0.22 and 0.19, in July - by 0.03 and 0.05, and in August, on the contrary, there was chlorophyll b content decrease by 0.21 and 0.22 mg/g of dry matter, respectively.

In 2014 small-leaved linden in CCZ plantations of industrial enterprises had chlorophyll b content in the leaves of plants higher than that of the CCZ plants during the whole period of active vegetation. The following dynamics of chlorophyll b content was detected in the leaves was recorded among the plants growing in the main plantations during both years of observations and in CCZ plants of industrial enterprises only in 2015: increase in June - by 0.04-0.25 and 0.20; increase in July - by 0.03-0.10 and 0.04; decrease in August - by 0.10-0.20 and 0.11 mg/g of dry matter, respectively.

Dispersion multifactor analysis of research results in 2014 and 2015 revealed a significant influence of species peculiarities ($P < 10^{-5}$), a set of conditions for cultivation area ($P<10^{-5}$), the periods of vegetation ($P<10^{-5}$), as well as the interaction of these factors ($P<10^{-5}$) on the content of carotenoids in the leaves of woody plants.

All studied woody plant species had a similar dynamics in the content of carotenoids: their increase in July compared to June, with some differences among the plant species in the plantations belonging to different environmental categories.

As for small-leaved linden the content of carotenoids in the leaves of plants at CCZ plantations of industrial enterprises and PA was really higher in June and July, and lower than among ZUK plants. A similar trend in the carotenoid content dynamics was typical for drooping birch and Norway maple in CCZ plantations of industrial enterprises and main plantations: the increase in June and a further decrease in July and August, in comparison with these values in ZUK. However, balsam poplar leaves had carotenoid content increase in June: in the plantations of sanitary protection zones of industrial enterprises by 0.37 and 0.21; in the main plantations by 0.13 and 0.09 mg/g of dry matter, respectively, in 2014 and 2015, as compared with this indicator of conditional control zone plantations at LSD_{05} = 0.01 mg/g of dry matter. Ash-leaved maple, which grows in the urban environment showed a significant decrease of carotenoids during the entire period of active vegetation as compared to ZUK during both years of research.

Summary

The nature of photosynthetic pigment content change in the leaves of the studied woody plant species in the plantations of different environmental categories is species-specific. Small-leaved linden and drooping birch growing in the plantations of sanitary protection zones of industrial enterprises and in main plantations the content of chlorophyll a and b decreases during the growing season in comparison with the plants in the plantations of conditional control zones, but at that the carotenoid content increases. Carotenoids have antioxidant properties and perform a protective function. Balsam poplar in main plantations has the increase of chlorophyll and carotenoid content in June, but then their reduction takes place, indicating other mechanisms of protection from man-made stress among this species. The representatives of the genus maple throughout the observation period in the city plantations had a significant decrease in the content of chlorophyll a in leaves. The aboriginal species - Norway maple - in main plantations during the beginning of active vegetation period in 2015, and in July 2014 as in plantations of sanitary protection zones of industrial enterprises, so as in main plantations, had an increase of chlorophyll b content in leaves compared with the plantings of conditional control zones, which indicates its participation in adaptive reactions. Maple ash - an introduced species - has a reduced chlorophyll b content during the period of active growth, as compared with the indicators in conditional control zone during the same interval. Besides, the species of maple genus had a carotenoid content increase in its leaves during June, which is likely due to their protective function during the initial stages of active plant growth.

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