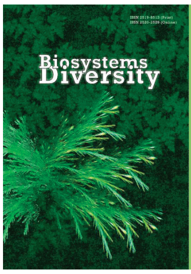

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The effect of vehicle exhaust emissions on morphometric and physiological characteristics of *Rhus typhina*

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Rhus typhina L. (Staghorn Sumac) is fast-growing woody species that reproduces by rhizomes and seeds. Because of its biological benefits, this deciduous member of the Anacardiaceae family has been introduced from its native habitats in the east of North America to urbanized landscapes of Ukraine. In this study we analyse changes in morphometric and physiological indicators of 12-year plants of this species in artificial phytocenoses near highways in Pavlograd, Ukraine. Experimental plots were placed at a distance from 25 to 130 meters from the road. The control group of plants was at a distance of 1500 m from the highways. We measured the length and thickness of the annual sprout, number of leaves on it, the content of chlorophyll in the leaves and accumulation of cadmium and lead in the leaf tissues. It was found that, compared to the plants in the relatively clean area, the greatest decreases in the length of the annual shoots of the trees in the plantations were for those which were at a distance of twenty five metres and forty meters from the traffic lanes of the highways. The thickness of the annual shoots of the trees in the plantations did not differ from plants in the clean zone. The number of leaves on a one-year annual sprout at a distance of twenty five meters and forty meters from the path of moving sources of pollution was significantly lower compared to control. We evaluated the impact of vehicle exhaust emissions on the assimilatory organs. We identified a negative effect of the anthropogenic pollutants on photosynthetic pigment content in leaves. The amount of chlorophyll *a* and chlorophyll *b* decreased with decreasing distance from the plantation to the road. Changes in the content of chlorophyll *b* had a clear pattern. The concentration of this pigment and the amount of chlorophyll *a* + *b* decreased compared with control in the 130 meter area. The amount of toxic heavy metals (lead and cadmium) in the tissues of the leaf was significantly higher than the control values on all plots. The strongest negative effects of phytotoxicants on susceptible plants occurred in plantations in the twenty-five-meter zone, which led to deterioration of the decorative quality of the plants.

Keywords: lead; cadmium; heavy metals; chlorophyll; growth; staghorn sumac.

Introduction

As a result of high anthropogenic load in cities, ecological problems have become especially sharp, particularly through the spread of chemical substances unfavourable for the environment and accumulation of excessive amounts of polluting compounds in the soil, water and living organisms which takes place in modern megapolises. The contribution made by autotransport to total atmospheric pollution in urbanized territories increases every year (Rolli et al., 2015). Vehicle emissions contain 1,000 polluting substances, but only 200 of them have been identified (Hooftman, 2016). Intensification of the emission of these aeropollutants into the biosphere is a global problem (Franco et al., 2013; Silva et al., 2016). The high level of saturation of urban territories with automobile transport, which increases every year, causes intensification of technogenic transformation processes in the environment of towns and cities. Some of the most dangerous xenobiotics which caused geochemical anomalies around roads and industrial centers (Maher et al., 2013; Werkenthin et al., 2014; Faly et al., 2017) are considered to be heavy metals such as lead and cadmium (Junaid et al., 2013; Hadi & Aziz, 2015; Suryawanshi, 2016; Martynov & Brygdyrenko, 2018). The abovementioned pollutants are contained in vehicle emissions and negatively affect the plants and animals in green planted areas (Lucychcyn, 2013; Youning, 2014; Brygadyrenko, 2016; Liang, 2017). Lead and cadmium belong to the category non-essential highly toxic elements, the useful role of which in biological processes of living organisms is currently undetermined. These metals are toxic even in small concentrations (Rolli et al., 2016).

The ability of the abovementioned phytotoxicants to accumulate in tissues of assimilating organs of plants of urban landscapes (Sawidis et al., 2011) leads to change in the structure and functioning of the entire organism (Parmar et al., 2013), exerting a long-term effect and after effect on their growth and development (Beramendi-Oroscoa & Hernandez-Alvarezc, 2013; Petrova & Velcheva; 2014).

The impact of heavy metals on plant organisms of phytocenoses near roads begins with their contact and consumption by assimilating organs. Leaves of tree plants have an important barrier function for distribution of pollutants on large distances. The assimilating apparatus of tree species has a large enough surface area for exchange with the environment, is able to absorb and settle significant amounts of dust and hazardous additives from the air (Grigoreva, 2015; Kentbayev & Abzhanov, 2015), but as a result of such environment-cleaning functions, is most damaged compared to other above-ground organs (Konoshina, 2015).

Cadmium and lead negatively affect the growth of tree species in the conditions of growth in a technogenic environment (Pihalo, 2014; Miller et al., 2015), causing changes in the morphological and anatomic structure of the assimilating organs (Smith, 2015; Bessonova & Kryvoruchko, 2017) and disorders in their functioning (Kopilova, 2013; Abbasi, 2017).

The abovementioned processes significantly damage the aesthetic value of urban plantations, especially on the territories around roads, and decrease their average filtrating property. The most efficient way of eliminating the negative effects of pollutants on phytocenoses is using tree species resistant to pollution (Kulakova et al., 2017). The range of such artificial groups consists of highly decorative, fast-growing, resistant introduced and native species. One of such tree species planted over the last decades is Staghorn Sumac (*Rhus typhina*). *Rh. typhina* comes from North America and has high decorative properties, high drought and winter resistance (Oleksijchenko et al., 2014), and is also used in medicine and industry (Wang & Zhu, 2017). The progressive strategies of reproduction (forming high number of root shoots) enables highly aesthetic mono-species groups to be created in urbanized territories over a relatively short period of time (Du et al., 2017).

Vehicle emission pollution of urban territories has a negative effect on the growth and development of Staghorn Sumac in plantations in technogenically transformed territories. However, the question of the use of this species for creating plantations in the territories around roads in cities of South-East Ukraine is practically unstudied.

The objective of the research was to analyse the impact of vehicle emissions on the morphometric and physiological parameters of one-year shoots of 12-year old plants of *Rh. typhina* L.

Materials and methods

The object of the study was 12-year old *Rh. typhyna* plants which grew on three study plots located at different distances from the road in the town of Pavlohrad. Plot 1 was located at the distance of twenty-five meters from the road surface, plot 2 – forty meters, plot 3 – one hundred and thirty meters. Control plants grew on plots located at the distance of 1,500 meters from the road, other sources of pollution were at the distance of over 10 km. The vehicle load on the road equaled 8,473 cars a day. The plots were selected using a randomized method. The agrochemical conditions were uniform within the plots. For the study, we used 10 model trees, the samples from which were taken from the model branches orientated towards the south-east. The increment of shoots and the area of the leaflets were determined using Molchanov's method (Molchanov & Smirnov, 1967). The samples of leaves of average formation on one-year shoots were selected from the south-east part of the crown at the height of 1.6–1.8 m from the soil surface in dry bright weather by 15 samples from ten trees from every plot at the same time. The chlorophyll content was determined after its extraction with 96% ethanol using SP-2000 spectrophotometer. The calculations were made using formulae of Wintermans and Mons (Bessonova, 2006). The content of heavy metals in the leaves was determined using atomic absorption spectroscopy (Bessonova, 2001) on an S-115 atomic absorption spectrometer. Morphological examinations were made in three replications, biochemical – five replications. The extent of vehicle load on the road was determined using the standard method (Maljugin & Parsaev, 2012).

The data were statistically analyzed using single-factor disperion analysis (ANOVA) and criterion of reliable differences of Tukey's test for average values of the groups.

Results

Rh. typhina plants which grew in artificial phytocenoses near the road, located at different distances from the road surface, were observed to have changes in morphological and physiological parameters. Growth processes in green plantations located in the zone twenty-five meters from the road were reliably inhibited by the vehicle emissions. At plot 1, the value of the annual increment was 39.5% lower compared to the conditions in the relatively clean zone (Table 1). At the distance of forty meters from the source of pollution (plot 2), this parameter was 28.9% lower than the control. The values of the length of annual increment in plants at plot 3 were at the level of the control. Thickness of one-year old shoots in the studied plants did not differ from the control parameters in all study plots.

Table 1
The impact of vehicle emissions on the parameters of one-year shoots of *Rh. typhina* (x ± SE, n = 25)

Plot	Shoot length, mm	% relative to the control	Thickness of shoot, mm	% relative to the control
Control	158.4 ± 7.91	100.0	10.00 ± 0.48	100.0
Plot 1 (25 m)	95.8 ± 4.60**	60.5	9.60 ± 0.33	98.5
Plot 2 (40 m)	112.6 ± 5.53*	71.1	9.85 ± 0.39	96.0
Plot 3 (130 m)	159.1 ± 7.84	100.4	9.79 ± 0.42	97.9

Note: * – difference between the control and experimental variant is statistically reliable at P < 0.05, ** – at P < 0.01.

Parameters of assimilating surface provide an informative indicator for analysis of changes in condition of plants in phytocenoses of urbanized territories. The number of leaves on one-year old shoots exposed to exhaust gas reliably decreased compared to the control at plots 1 and 2 (Table 2). The values of this parameter decreased more in the plants which grew in the zone twenty-five meters away from the road (plot 1) – by 13.2% compared to the control. At forty meters from the road (plot 2), the reduction in this parameter equaled 9.7%. The parameters of leaves from plot 3 did not reliably differ from the parameters in the relatively clean zone.

Table 2
Impact of vehicle emissions on the assimilation apparatus of *Rh. typhina* (x ± SE, n = 25)

Plot	Number of leaves per shoot, specimens	% relative to the control	Area of leaf, cm^2	% to the control	Area of assimilating area of shoot, cm^2	% relative to the control
Control	9.25 ± 0.31	100.0	269.6 ± 13.5	100.0	2493.8 ± 124.3	100.0
Plot 1 (25 m)	8.03 ± 0.37*	86.8	231.2 ± 11.7**	85.8	1962.4 ± 97.2*	78.7
Plot 2 (40 m)	8.36 ± 0.28*	90.4	255.7 ± 12.1	94.7	2137.6 ± 105.9*	85.7
Plot 3 (130 m)	9.15 ± 0.46	98.9	261.4 ± 12.8	97.0	2391.8 ± 118.1	95.9

Note: see Table 1.

Changes in the number of leaves on shoots of woody plants on the territories polluted with exhaust gas have been determined by a number of authors. Negative impact of the above-mentioned pollutants on this parameter was determined for silver birch (Pihalo, 2014), rowan (Kolon et al., 2013), common lilac (Bessonova, 2006).

The area of non-paripinnate leaves of Staghorn Sumac was determined by the number and area of leaves on the rachis. In the conditions of exposure to vehicle emissions, an insignificant decrease of the area of the leaf occurred. At plot 1, leaves on the rachis of the studied plants had a smaller area compared to the control. The area of the leaf at a distance of twenty-five meters from the road was reliably smaller by 14.2% compared to the control. At plots 2 and 3, the value of the parameter did not reliably differ from that in the relatively clean zone.

In the conditions of exposure to exhaust gases, the area of assimilating surface did not significantly decrease. The value of this parameter among plants which grew at a distance of twenty-five (plot 1) and forty meters (plot 2) decreased by 21.3% and 14.3% compared to the control. On plot 3, the difference between the values of this parameter in relation to relatively clean zone was not reliable. Therefore, environmental pollution of the environment with vehicle emissions caused inhibition of growth of one-year old shoots and their structural elements in the zone forty meters from the road.

One of the most important characteristics of activity and development of photosynthesis apparatus in the unfavourable conditions of urbanized territories is the content of plastid pigments. The impact of vehicle emissions on the content of chlorophyll *a* in the leaves of Staghorn Sumac caused a reliable decrease in concentration of the latter on the study plots (Table 3). The content of chlorophyll *a* on plot 1 decreased compared to the control by 40.0%.

Table 3
Impact of vehicle emissions on the content of pigments (mg/g of raw mass) in leaves of *Rh. typhina* (x ± SE, n = 5)

Plot	Chlorophyll *a*	% relative to control	Chlorophyll *b*	% relative to control	Chlorophyll *a+b*	% to the control	Chlorophyll *a/b*	% relative to control
Control	1.35 ± 0.05	100.0	0.66 ± 0.03	100.0	2.14 ± 0.10	100.0	2.04 ± 0.09	100.0
Plot 1 (25 m)	0.81 ± 0.04**	60.0	0.55 ± 0.02*	83.3	1.36 ± 0.06*	63.6	1.47 ± 0.07*	72.5
Plot 2 (40 m)	1.05 ± 0.05*	77.8	0.54 ± 0.03**	81.8	1.68 ± 0.10*	78.5	1.94 ± 0.09	95.1
Plot 3 (130 m)	1.22 ± 0.03*	90.4	0.58 ± 0.01*	87.9	1.80 ± 0.09*	84.1	2.10 ± 0.10	102.9

Note: see Table 1.

On plots 2 and 3, decrease in the values of this parameter equaled 22.2% and 9.6% respectively. In plants exposed to vehicle emissions, the amount of chlorophyll *b* decreased. It should be mentioned that its concentration was reliably lower than the control on the all studied plots. The difference compared to the parameters in the relatively clean zone was observed on plots 1 and 2 at almost the same level – by 18.2% and 16.7%. On plot 3, the decrease equaled 12.1%. Therefore, on the all experimental plots which were in the zone of impact of the vehicle emissions, the amount of chlorophyll a and b reliably decreased.

Analysis of the content of the total of chlorophyll $a + b$ revealed a decrease in the parameter on the experimental plots (Table 3). The largest reliable decrease compared to the relatively clean zone was observed at the distance of twenty-five meters (plot 1) – by 36.4%. On the plots 2 and 3, this parameter differed by 21.5% and 15.9% respectively.

Change in the ratio of *a/b* chlorophyll in plants exposed to the ingredients of vehicle emissions reliably decreased in the leaves of plants which grew on plot 1. The value of this parameter decreased by 27.5% compared to the control. On the other plots, no reliable changes in the parameters were found.

In the leaves of *Rh. typhina*, such heavy metals as Cd and Pb, which are contained in vehicle emissions, accumulate (Table 4). On plot 1, the concentration of the abovementioned xenobiotics exceeded the parameters in the relatively clean zone by 20.4% (lead) and 59.0% (cadmium).

Table 4
Content of heavy metals in the leaves of *Rh. typhina*
in the conditions of pollution with vehicle emissions ($x \pm SE$, $n = 5$)

Plot	Pb, mg/kg	% to the control	Cd, mg/kg	% to the control
Control	4.37 ± 0.21	100.0	0.39 ± 0.02	100.0
Plot 1 (25 m)	5.26 ± 0.24**	120.4	0.62 ± 0.03*	159.0
Plot 2 (40 m)	5.42 ± 0.20*	124.0	0.50 ± 0.02**	128.2
Plot 3 (130 m)	5.05 ± 0.18*	115.6	0.47 ± 0.01*	120.5

Note: see Table 1.

Increase in the distance from the road surface to forty meters (plot 2) did not significantly affect the content of lead – the parameters were higher than the control by 24.0%, but did not reliably differ from this on plot 1. The concentration of cadmium in leaf tissues of leaves on plot 2 was higher than the control parameters by 28.2%. At the distance of one hundred and thirty meters (plot 3) from the road, the content of lead and cadmium was higher than in the relatively clean zone by 15.6% and 20.5% respectively.

Discussion

The large amount of vehicles on the roads of modern cities (Fu, 2017) leads to an increase in the toxic substances in the air (Panko et al., 2013), which has a negative effect on trees, inhibiting their growth and development (Mamieva & Shirnina, 2017). An informative indicator of their condition in the pollution is intensivity of growth. Analysis of our study's results demonstrated the presence of reliable inhibition of growth of one-year old shoots of twelve-year old *Rh. typhina* at the distance of twenty five and forty meters from the road surface. Growth inhibition of shoots of trees which grew in the conditions of environmental pollution with vehicle emissions has been determined by a number of authors (Rai, 2016; Dzhygan, 2017; Mamieva & Shirnina, 2017).

Increment of the organic mass of plants is mostly determined by development and condition of the assimilating surface. Numerous studies have indicated a clear tendency towards decrease in the area of total leaf surface of shoots and disorders in photosynthesis processes of plants exposed to vehicle emissions (Parmar et al., 2013).

One of the most important characteristics of the photosynthetic apparatus, which conditions its activity, is the content of chlorophylls. Photosynthetic activity as an informative indicator of the condition of woody plants was used by the researchers studying the impact of stress factors, including heavy metals, which inhibit processes of photosynthesis, (Bessonova, 2006). Concentration of plastid pigments in the leaves depends on anthropogenic and natural factors. Changes in the content of pigments have a non-specific pattern and are used as a marker of pollution of artificial phytocenoses with pollutants of anthropogenic origin (Parmar et al., 2013). For the functioning of the photosynthetic apparatus, it is important to retain a certain proportion of *a* and *b* chlorophylls. Change in this parameter in plants exposed to unfavourable ecological factors reflects the functioning of chloroplasts, and therefore a number of authors consider the chlorophyll *a/b* ratio more informative than the concentration of each of them (Lindahl et al., 1995; Shupranova et al., 2017). In the work by Shupranova et al. (2017), the proportion of chlorophylls *a/b* in the conditions of pollution with vehicle emissions was at the same level in leaves of *Quercus robur* of I and II classes of vitality, and by 29.3% lower in the III vitality class compared to the values of control.

According to our studies, the plants that grew at the distances of 40 and 130 m from the road had a reliably decreased concentration compared to the relatively clean zone but the proportion of these pigments remains at the level of the control. It should be mentioned that for 4–6 year old *Rh. typhina* plants at the distance of 25 m from the road changes of both total of the chlorophylls and their proportion were not reliably different from the values in the relatively clean zone (Dzhygan, 2017). Absence of reliable difference in the abovementioned parameters, in some authors' opinion (Bessonova, 2006) has great significance and is an adaptive reaction, using by which a plant adapts to the impact of xenobiotics.

Fluctuations in chlorophyll concentration can be explained only by accumulation of Cd and Pb – heavy metals contained in vehicle emissions. In the leaves of the studied plants, the cadmium content ranged 0.39–0.62 mg/kg of dry weight. According to Kabatta-Pendias & Pendias (2001), the background content of this element in plants was 0.05–0.80 mg/kg, and toxic content – 1.0–70.0 mg/kg of dry weight. During the period of our study, cadmium concentration did not reach the lowest border of the toxic range, but was 1.2–1.6 times higher than the control. The increase in the cadmium content in the leaves of trees of street plantations was mentioned in reports by Mamieva & Shirnina (2017) – leaves of small-leaved lime in the phytocenoses near roads contained by 65.2–113.2% more cadmium compared to the control. A 15 fold excess over the background content of the abovementioned pollutant was found in leaves of *Acer platanoides* (Valetov et al., 2017).

Content of lead in technogenically transformed environments continuously increases (McPherson, 2016). This is related to use of its compounds in vehicle fuel and increase in the vehicle load on the roads (Franco et al., 2013; Salam et al., 2013). The major part of the abovementioned pollutants introduced to plants of cultivated-phytocenoses of modern settlements, especially oblast and district centers, come from exhaust gas. The phytotoxicant and its compounds are able to penetrate the root system and be absorbed from the air by leaves (Hadi & Aziz, 2015). It was determined that accumulation of lead in tissues of leaves causes changes in their structure (Polonsky & Polyukova, 2014; Bessonova & Kryvoruchko, 2017) and functioning (Kulagin & Kuzhleva, 2005; Neverova & Tsandekova, 2010; Sawidis, 2011). In plants which grow in relatively clean territories, the concentration of the abovementioned toxicant ranges from 0.1 to 10 mg/kg of dry weight (Kabatta-Pendias & Pendias, 2001). The content of lead in the assimilating organs of *Rh. typhina* in the conditions of pollution with vehicle emissions was within this range, but was 1.1–1.2 times higher than the control values. Some authors (Rolli et al., 2016; Mamieva & Shirnina, 2017; Valetov et al., 2017) reported increase in lead concentration in assimilating organs of plants in plantations near roads. In the conditions of the impact of vehicle emissions, in the leaves of small-leaved lime (*Tilia cordata*), the lead content was higher than the control values by 28.3% (Mamieva & Shirnina, 2017). In *Acer platanoides* L. the content of this heavy metal equalled 1.30 mg/kg of dry weight, while *T. cordata*, *Fraxinus exelior*, *Robinia pseudoacacia* had an increased content of lead compared to the conditions of the clean zone (Valetov et al., 2017).

Vehicle emissions inhibited growth processes of twelve-year old plants of *Rh. typhina* in the zone forty meters away from the road, which decreases their decorative value. At the distance of over forty meters away from the road, changes in the concentration of chlorophyll and heavy metals occur without growth inhibition of shoots and decrease in the parameters of assimilating surface. Therefore, 12 year-old plants of *Rh. typhyna* can be recommended for creating artificial phytocenoses at over forty meters distance from a road. Further, it is necessary to conduct studies of the molecular mechanisms of resistivity of *Rh. typhina* to vehicle emissions for improving agrotechnical measures for taking care of this species in zones polluted with vehicle emissions.

Conclusions

Growth of *Rh. typhina* trees in the zone forty meters away from the road surface negatively affects the annual increment of shoots, the number of leaves on them and the area of assimilating surface. The severest inhibition affected the growth processes in plants which grew at the distance of twenty-five meters. At the distance of one hundred and thirty meters (plot 3), the abovementioned parameters did not reliably differ from those in the relatively clean zone. Thickness of one-year old shoots remained at the level of control values on all experimental plots.

Decrease in concentration of chlorophyll a in the leaves was determined for *Rh. typhina* plants which grew on the all experimental plots. The most significant decrease in this parameter took place on the plot 1. As the distance from the road increases, the impact of the pollutant weakens. The content of chlorophyll b decreased under the impact of vehicle emissions.

The abovementioned changes in the content of pigments are explained by accumulation of heavy metals such as cadmium and lead in leaves. The content of these pollutants exceeded the norm for the relatively clean zone on the all study plots. Increase in concentration of these pollutants was the highest compared to the control on plot 1 (cadmium) and plot 2 (lead).

Accumulation of lead and cadmium, which exceeds the values of relatively clean zone and reduction of the chlorophylls' concentration caused no disorders in the growth of trees that grew at the distance of 130 m from the road and did not significantly decrease their decorative value. Twelve year old plants of *Rh. typhina* can be recommended for creating artificial phytocenoses at a distance of one hundred and thirty meters distance from a road.

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