Екологія

DOI 10.32782/NSER/2023-1-9
UDC 504.064

ENVIRONMENTAL MONITORING IN DROHOBYCH BY BIOINDICATION METHOD

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An influence of anthropogenic load on the morphological and physiological parameters of indicator plants (Tilia cordata, Acer platanoides, Carpinus betulus) in Drohobych was studied. Plants were selected according to their sensitivity to changes in the environment and its degree of pollution. The choice was also due to the fact that these trees are often used for landscaping; and they are found on all the streets chosen for the study. According to the results of the study, the growth of the assimilation organ can be reproduced in the next consecutive series: Park Novonarodzhenykh → Center → Sambirska Street → Stryjska Street.

Analysis of the degree of asymmetry of leaves of indicator plants showed that the largest values of the degree of difference in the characteristics of leaves of woody plants are characteristic of individuals that grew within the zones with the highest level of anthropogenic pressure – Sambirska Street and Center.

Necrotic changes of leaf blades in different regiond of Drohobych were estimated, the maximum value of necrotic lesions of the leaf blade is typical for woody plants in the zones: Center (0.51–16.88%) and Stryiska street (1.63– 10.04%). The most characteristic types of necrotic lesions for Carpinus betulus are interveinal, Tilia cordata – spotted, Acer platanoides – spotted. The increase in the necrotic surface is a consequence of the total load on the city's ecosystem. The highest level of necrotization was established on Sambirska Street for all species of indicator plants. The results show that the most resistant to anthropopression is Carpinus betulus, and the most vulnerable species – Tilia cordata. This makes linden a valuable bioindicator of condition of the atmospheric air.

Assessment of the environment of Drohobych by morpho-physiological indicators of indicator plants indicates its significant pollution, revealed changes in morphometric parameters, increasing the degree of asymmetry, increasing the level of necrotization and photosynthetic function due to reduced chlorophyll a and b. This trend is most clearly traced on Stryjska Street and in the Center.

Key words: *bioindication, anthropogenic pressure, indicator plants, asymmetry, necrotization, photosynthesis.*

Гойванович Н. К. Моніторинг стану довкілля м. Дрогобич методом біоіндикації

Реалізовано комплексний моніторинг впливу антропогенного навантаження на морфофізіологічні показники рослин-індикаторів (Tilia cordata, Acer platanoides, Carpinus betulus) у Дрогобичі. Рослини відбирали за чутливістю до змін навколишнього середовища та ступенем його забруднення. Вибір також був зумовлений тим, що ці дерева часто використовують для озеленення міста; і вони трапляються на всіх досліджуваних вулицях. За результатами дослідження збільшення площі листкових пластинок можна відтворити в такій послідовності: Парк Новонароджених → Центр → вулиця Самбірська → вулиця Стрийська.

Аналіз ступеня асиметрії листя рослин-індикаторів показав, що найбільші значення характерні для деревних рослин, які зростали в межах зон з найвищим рівнем антропогенного навантаження – вул. Самбірська та Центр.

Оцінено некротичні зміни листкових пластинок у різних районах м. Дрогобича, максимальне значення некротичного ураження листкової пластинки характерне для деревних рослин у зонах: Центр (0,51–16, 88%) та вул. Стрийська (1,63–10,04%). Найбільш характерними типами некротичних уражень для Carpinus betulus є міжжилкові, Tilia cordata – плямисті, Acer platanoides – плямисті. Збільшення некротичної поверхні є наслідком загального навантаження на екосистему міста. Найвищий рівень некротизації встановлено по вул. Самбірській для всіх видів рослин-індикаторів. Результати

показують, що найбільш стійким до антропопопресії є Carpinus betulus, а найбільш вразливим видом – Tilia cordata. Це робить липу цінним біоіндикатором стану атмосферного повітря.

Оцінка довкілля м. Дрогобича за морфо-фізіологічними показниками рослин-індикаторів свідчить про його значне забруднення, виявлено зміни морфометричних показників, підвищення ступеня асиметрії, підвищення рівня некротизації та фотосинтетичної функції за рахунок зниження вмісту хлорофілу a та b. Найбільш чітко ця тенденція простежується на вул. Стрийській та у Центрі.

Ключові слова: *біоіндикація, антропогенний тиск, рослини-індикатори, асиметрія, некротизація, фотосинтез.*

Introduction. Anthropogenic pressure in ecosystems is one of the most important problems of today's ecology, because it is one of the causes of environmental pollution, and this effect is further reflected in plants, their morphological parameters and ability to photosynthesis [1; 10]. A significant share of the negative impact on the state of modern ecology is the impact of the motor complex, which pollutes the air with emissions of more than half. Assessing the quality of the urban environment, saturated with a variety of sources of air pollution is of great practical importance. The use of physical, physico-chemical, chemical methods with their high accuracy can not create a complete picture of the environmental situation because it is toxic at the same time. Instrumental control provides information on the concentrations of pollutants in the air at present.

According to international environmental regulations, environmental monitoring in all countries should be carried out taking into account national characteristics on the basis of general UN recommendations. The documents stipulate that the basis of the level of national monitoring of the CIS countries is a geophysical approach – monitoring the state of certain environments (atmosphere, hydrosphere, soils) of the biosphere. According to the Law of Ukraine "On Environmental Protection" and "Regulations on State Environmental Monitoring" in Ukraine is developed and implemented a system of environmental monitoring. This involves environmental monitoring, collection, processing, evaluation of results and forecasting its status, the formation of appropriate databases, development on their basis of scientifically substantiated nature protection measures, anticipation of emergencies of technogenic, natural character, creation of safe conditions [5; 9].

Bioindication is a method of identifying and determining ecologically significant natural and anthropogenic loads based on the reactions of living organisms to them directly at the place of their existence. Biological indicators have features inherent in the system or process, on the basis of which a qualitative or quantitative assessment of trends, determination or evaluation of the state of ecological systems, processes and phenomena [7]. At present, it can be generally accepted that the main indicator of sustainable development is ultimately the quality of the habitat.

Atmospheric air of urban environments is characterized by a significant level of pollution caused by industrial waste (smoke, dust, small particles of coal, vapors of strong acids, carbon oxides, etc.), which are deposited on growing plants and cause inhibition of growth, etc. [4; 7].

Vegetation changes under the influence of various environmental factors affect the state of the biogeocenosis as a whole and, consequently, can be used as diagnostic features. Information on structural and functional disorders, the nature of the receipt, transformation and accumulation of toxicants in plant organs in a man-made environment can be obtained using various methods (anatomical, physiological, biochemical, etc.) [8].

The most sensitive indicator of the condition of plants is the photosynthetic apparatus [1]. In some species of plants, the peculiarities of growth and development change (growth slows down or accelerates, the process of flowering, fruit formation changes, the intensity of color changes, etc.) in response to various environmental factors. Mankind has long noticed these properties and used them for practical purposes. Due to the general greening of various scientific fields, human thinking in general, bioindication methods are increasingly used by modern scientists, including in environmental monitoring.

Therefore, due to the need for global monitoring, the use of indicative capabilities of biological objects is becoming increasingly important. Plant indicators are used both to detect individual contaminants and to monitor the general state of the environment. The use of woody plants as accumulators of urban man-made pollutants and bioindicators of the ecological state of the environment serves as a theoretical basis for the creation of ecologically efficient crops of phytocenoses in urban ecosystems [4; 8].

During 2018–2022 environmental monitoring of the Lviv Region is being carried out. The analysis of the results of environmental monitoring in the cities of Stryi, Stebnyk, and Stariy Sambir by the method of bioindications indicates a significant level of anthropopression [2; 3; 12]. The aim of the work is to assess the state of the environment of Drohobych by morpho-physiological indicators of indicator plants: linden (*Tilia cordata*), maple (*Acer platanoides*) and hornbeam (*Carpinus betulus*).

Materials and methods. Laboratory tests were performed in the laboratory "Microbiology and Genetics"

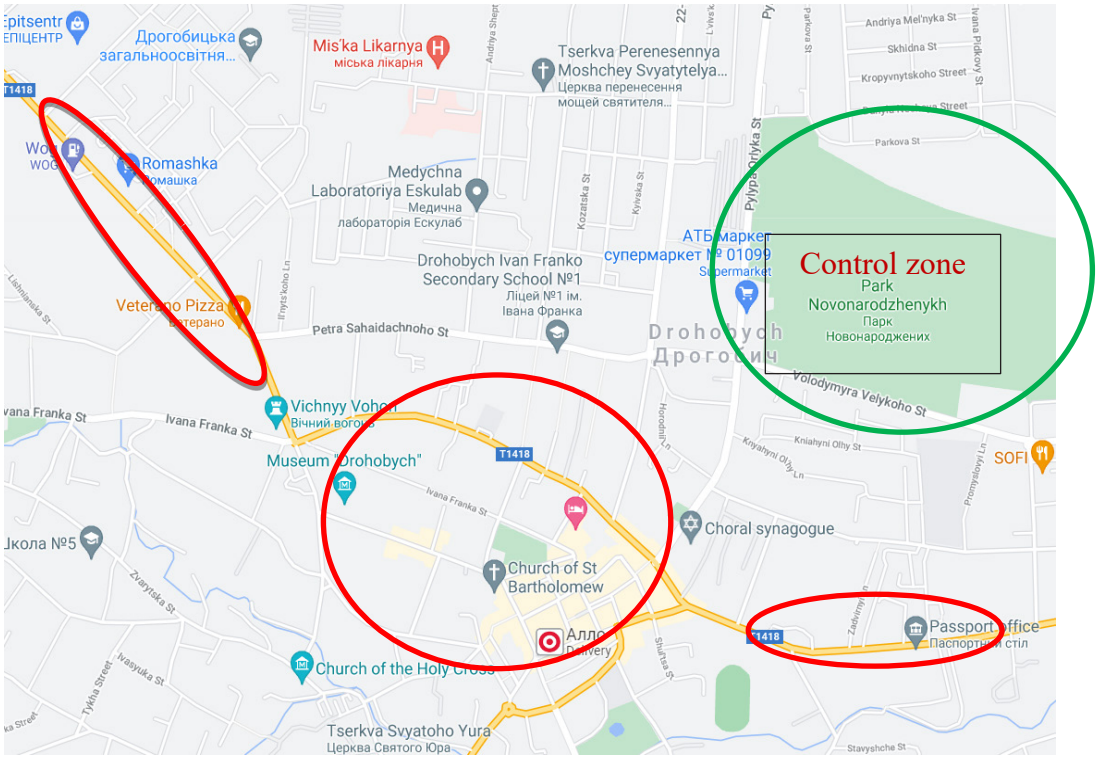

Fig. 1. Map of Drohobych

Drohobych Ivan Franko State Pedagogical University at the end of the growing season (2020–2021). To solve the tasks was used weighing method with modification L. Dorogan with the establishment of the conversion factor. Detection of necrotic and depigmentation damage to the leaves of woody indicator plants was carried out visually. Classification of the detected lesions of the leaf was performed using the scheme proposed by R. Schubert [4; 7].

The research was conducted in the following areas of Drohobych: Stryjska street, Park Novonarodzhenykh, city center, Sambir street. The background area is the Park Novonarodzhenykh. The experimental plots on the map are marked with a red line (Figure 1). Three species of trees were selected for the experiment: linden (*Tilia cordata*), maple (*Acer platanoides*) and hornbeam (*Carpinus betulus*). Because these trees are in all four study areas.

Disscusion. The city of Drohobych has a well-developed infrastructure, industrial areas, about 80 thousand population, significant traffic. Therefore, it is advisable to study the effect of anthropogenic pressure on the morphological changes of indicator plants: *Tilia cordata, Carpinus betulus* and *Acer platanoides*. Fixation and evaluation of morphometric parameters give a reliable picture of the conditions of plant growth and reflect the state of the urban environment [1; 8]. Data on changes in the area of leaf blades of plants-bioindicators were entered in table 1.

Table 1

The area of leaf blades of indicator plants in different areas Drogobych

№	Research area	Indicator	Leaf area, cm²
1	**Center**	*Carpinus betulus*	39.4±4.32
		Tilia cordata	48.9±3.29
		Acer platanoides	113.1±10.7
2	**Sambirska Street**	*Carpinus betulus*	47.9±3.6
		Tilia cordata	55.2±7.83
		Acer platanoides	159.6±12.42
3	**Park Novonarodzhenykh**	*Carpinus betulus*	34.2±4.5
		Tilia cordata	42.55±6.78
		Acer platanoides	96±4.99
4	**Stryjska Street**	*Carpinus betulus*	48.2±6.53
		Tilia cordata	54.26±6.68
		Acer platanoides	166.1±17.81

Due to the influence of the polluted environment of Drohobych, significant changes in the area of leaf blades were revealed. Studies have shown an increase in the leaf blade of woody plants in Drohobych. The maximum deviations of this indicator were observed for Stryjska and Sambirska streets for all three studied trees. Significant deviations of this parameter in the specified areas of the city of Drohobych can be caused by influence of the technogenic factor which is especially expressed on these streets owing to transport pollution of environment. [2].

The most sensitive to environmental pollution was the maple (*Acer platanoides*). After all, the increase

in leaf blade compared to the background area, the Park Novonarodzhenykh, is much greater in the other three study areas.

The increase in the area of leaf blades may be due to the need to increase photosynthesis in conditions of anthropogenic pollution. Probably, this is an adaptive property to increase the intensity of gas exchange [8].

Since the leaves of plants are symmetrical structures, the deviation of this indicator is also an indicator of contamination in plants of bioindicators. All selected material was analyzed in the laboratory for 1–3 days. The results obtained are presented in table 2.

Table 2

Difference of features of leaves of indicator plants in Drohobych

Research area	The relative average difference between the features					
	Tilia cordata		Acer platanoides		Carpinus betulus	
Center	0.055	2 p	0.058	2 p	0.060	3 p
Sambirska Street	0.060	3 p	0.061	3 p	0.069	4 p
Park Novonarodzhenykh	0.043	1 p	0.042	1 p	0.048	1 p
Stryjska Street	0.059	2 p	0,.057	2 p	0.064	3 p

The results showed that the smallest asymmetry of the leaf blade has a heart-shaped linden, in all areas of this study, from 0.042 to 0.060, which is considered a clean and relatively clean area. According to the study, the greatest asymmetry of the leaf blade was found in hornbeam, from 0.060 to 0.064, and this symbolizes the level of "alarm".

It should be noted that the longer the period of anthropogenic pressure on the plant during the growing season, the more pronounced the level of asymmetry.

According to this study, the level of anthropogenic load on the territory of Drohobych on the streets of Stryjska and Sambirska is above average. There is an increase in the degree of divergence of leaf characteristics, proportional to the level of anthropogenic load on ecotopes. The analysis of the obtained data revealed the signs most prone to asymmetry – the width of half of the leaf and the angle between the main vein and the second from the base of the vein of the second order.

Various industrial and transport pollutants can cause necrosis and various damage to the leaves of plants that grow under conditions of industrial and transport pollution. The effects of pollutants are manifested on plants not only near the sources of pollution, but also within a radius of tens and hundreds of kilometers outside the industrial facilities [10; 11].

External signs of tree damage are of different nature from discoloration, necrosis of assimilation organs, to earlier leaf fall, underdevelopment of shoots, complete death of plants.

From the results of the study revealed pathological changes (necrotic and dechromatic lesions of the leaf blades) have a pronounced species-specific nature. The most characteristic types of necrosis for *Carpinus betulus* are spotted, heart-shaped *Tilia cordata* – interstitial, *Acer platanoides* – spotted.

The maximum value of necrotic lesions of the leaf blade was observed in Acer platanoides (16.88%), which was collected on Stryjska Street, the minimum – in Carpinus betulus (0.51%) – in the center.

It is established that in all zones of the city the damages are formed by spotty, point and interveinal necrosis and dechromation. Such damage occurs due to deep irreversible changes in the leaf blade due to the penetration of a significant mass of pollutants into the environment [13].

Unambiguously visible necrosis in the spring was not found, probably due to the relatively short duration of contaminants of plant leaves of trees (because the leaves of trees are formed new in each growing season), better metabolism in young leaves and the concentration of harmful substances in the leaf.

In recent years, the notion of the dependence of the direction and productivity of photosynthesis on the action of factors that can significantly affect the content of chlorophyll and their functional activity. Therefore, the study of the dynamics of chlorophyll accumulation in plant leaves under the influence of chemical and biological factors is of great importance because its content affects the intensity of photosynthesis and a number of other physiological processes [1].

Determination of pigments of chlorophylls and carotenoids (the main photoreceptors of plant cells) was carried out in the autumn, namely in September. This made it possible to see the main dynamics of changes in the concentration of chlorophyll a and b, and carotenoids in the leaves of indicator plants in Drohobych at the end of the growing season depending on the area of growth of the indicator plant.

Paying attention to the previous results, we can conclude that the plants have started degradation processes (intensification of asymmetry, increasing the level of necrotization), the study of the pigment composition of linden, maple and hornbeam in terms of pollution of the city ecosystem will analyze in detail the physiological processes in plants under the action of harmful substances [4; 8].

The concentration of chlorophyll a in the leaves of linden varies between 20.52–35.44 mg/l, but the rate of chlorophyll on the street. Stryiska is no different from the background area. In the leaves of maple sharp-leaved chlorophyll a varies in the range of 29.69–34.48 mg/l, and hornbeam – 25.08–36.93 mg/l. In general, the indicators occupy an average position, the worst indicators are recorded on Stryjska Street and in the Center.

Table 3

The content of pigments in the raw mass of leaves of indicator plants in Drohobych

№	Research area	Species of indicator	$A_{chl/a}$	$A_{chl/b}$	A_{car}
1	Park Novonarodzhenykh	*Tilia cordata*	4.30	0.94	1.74
		Acer platanoides	3.99	2.74	1.63
		Carpinus betulus	4.61	0.49	1.64
2	Stryjska Street	*Tilia cordata*	4.43	1.32	1.52
		Acer platanoides	3.68	0.30	1.23
		Carpinus betulus	3.13	0.40	0.99
3	Sambirska Street	*Tilia cordata*	3.61	1.12	1.27
		Acer platanoides	4.31	1.59	1.68
		Carpinus betulus	4.36	1.61	1.44
4	Center	*Tilia cordata*	2.5	0.59	1.12
		Acer platanoides	3.99	2.29	1.57
		Carpinus betulus	4.4	1.16	1.69

Evaluation of the effect of anthropogenic pollution on the concentration of chlorophyll b in the leaves of indicator plants showed that the amount of this pigment varies slightly, this is best seen in the example of h Carpinus betulus.

The concentration of carotenoids in the leaves of indicator plants is almost unchanged depending on the habitat. This may indicate the stability of this pigment against the action of anthropogenic load.

Paying attention to the concentration of photosynthetic pigments in woody plants, we can conclude that it varies depending on the place of growth of the plant. The highest concentration of pigments is recorded in the Park Novonarodzhenykh, which may indicate less anthropogenic impact on the environment. The lowest is in the Center and on Stryjska Street, which indicates greater anthropopressing for the environment.

Thus, the assessment of the state of the environment of the city of Drohobych on the morpho-physiological parameters of indicator plants (*Tilia cordata, Acer platanoides, Carpinus betulus*) indicates its pollution. According to the results of research, changes in morphometric parameters, increase in the degree of asymmetry, increase in the level of necrotization and violation of photosynthetic function due to a decrease in the concentration of chlorophyll a and b were found in plants. This trend is most clearly seen on Stryjska Street and in the Center.

Results. Environmental monitoring of Drohobych by the method of bioindication, morpho-physiological parameters of trees of indicator plants (*Tilia cordata, Acer platanoides, Carpinus betulus*) was carried out. It was found that in Drohobych there is an increase in the area of leaf blades in the studied tree species, probably due to the increase in the intensity of photosynthesis and gas exchange in plants. These changes were most pronounced for Acer platanoides at the end of the growing season. Analysis of the level of asymmetry of the leaves of indicator plants showed that these changes are most pronounced in Carpinus betulus at the end of the growing season. In general, the level of asymmetry decreased in this direction Sambirska Street → Stryjska Street → Center → Park Novonarodzhenykh.

Necrotic changes of leaf plates in different districts of Drohobych were evaluated. For Tilia cordata and Acer platanoides, the highest level of necrotic damage was found Sambirska Street, respectively, 9.9% and 16.9%. Carpinus betulus is a resistant species to necrosis, its damage is minimal 2.29%. An assessment of the state of the photosynthetic apparatus is given. It was found that the concentration of photosynthetic pigments in the leaves is reduced in the Center and on Stryjska Street, which indicates some contamination of these areas. Thus, the established changes give grounds to assert that in the conditions of Drohobych there is not a significant anthropogenic pressure on woody indicator plants.

Bibliography:

1. Гетко Н.В. Рослини в техногенному середовищі. Структура та функція асиміляційного апарату. Мінськ : Наука і техніка, 2001. 308 с.
2. Гойванович Н.К., Дрозд І.Ф. Вплив антропогенного навантаження на морфометричні показники рослин-індикаторів в умовах Передкарпаття України. *Розвиток природничих наук: проблеми та рішення* : матеріали Міжнародної науково-практичної конференції, 27–28 квітня 2018 р. Брно, 2018. С. 16–19.
3. Гойванович Н., Юзьвяк М., Біла В. Оцінка стану навколишнього середовища м. Старий Самбір за морфо-біологічними змінами *Tilia cordata. Екологічні науки*. 2022. № 3(42). С. 211–216.
4. Гродзинський Д.М., Шиліна Ю.В., Куцоконь Н.К. Застосування рослинних тест-систем для оцінки комбінованої дії факторів різної природи. Київ : Фітосоціоцентр, 2006. 60 с.
5. Екологічні паспорти Львівської області за 2018–2021 р. URL: https://deplv.gov.ua/ekologichnyj-pasport/ (дата звернення: 05.09.2021).
6. Купчик О.Ю. Викиди автомобільного транспорту як джерело забруднення атмосферного повітря міста Чернігова. *Молодий вчений*. 2015. № 2 (17). С. 17–20.
7. Осика В.Ф. Якість вимірювань складу та властивостей об'єктів довкілля та джерел їх забруднення : монографія. Київ : Наука, 2001. 663 с.
8. Приседський Ю.Г. Адаптація рослин до антропогенних чинників : підручник для студентів вищих навчальних закладів. Вінниця : ТОВ «Ніланд-ЛТД», 2017. 98 с.
9. Регіональна доповідь про стан навколишнього природного середовища Львівської області (2018–2020 рр.). Міністерство захисту довкілля та природних ресурсів України. URL: https://menr.gov.ua/ (дата звернення: 04.06.2021).

10. Barabash O., Lozova T., Kozlova T. Assessment of the urban environment quality in Kyiv. *Acta Carpathica*. 2017. № 28. P. 5–12.
11. Franiel I. Fluctuating asymmetry of Betula pendula Roth. leaves – an index of environment quality. *Biodiv. Res. Conserv*. 2008. Vol. 9–10. P. 7–10.
12. Hoivanovych N., Pavlyshak Ya., Antonyak H. Influence of anthropogenic load in the city of Stryi on the functional state of photosynthetic apparatus of plants-indicators. *Acta Carpathica.* 2019. № 31–32. P. 52–59.
13. Velickovi M. Developmental stability in Tilia cordata leaves. *Period biol*. 2010. Vol. 112, № 3. P. 273–281.

References:

1. Hetko N.V. (2001) Roslyny v tekhnohennomu seredovyshchi. Struktura ta funktsiia asymiliatsiinoho aparatu [Plants in man-made environment. Structure and function of the assimilation apparatus]. Minsk: Nauka i tekhnika, 308 s. [in Ukrainian]
2. Hoivanovych N.K., Drozd I.F. (2018) Vplyv antropohennoho navantazhennia na morfometrychni pokaznyky roslyn-indykatoriv v umovakh Peredkarpattia Ukrainy [The influence of anthropogenic load on the morphometric parameters of indicator plants in the Precarpathian region of Ukraine]. Rozvytok pryrodnychykh nauk: problemy ta rishennia: materialy Mizhnarodnoi naukovo-praktychnoi konferentsii, 27–28 kvitnia 2018 r. Brno, S. 16–19. [in Ukrainian]
3. Hoivanovych N., Yuzviak M., Bila V. (2022) Otsinka stanu navkolyshnoho seredovyshcha m. Staryi Sambir za morfo-biolohichnymy zminamy Tilia cordata [Assessment of the state of the environment of Staryi Sambir on morpho-biological changes of *Tilia cordata*]. Ekolohichni nauky, № 3(42), S. 211–216. [in Ukrainian]
4. Hrodzynskyi D.M., Shylina Yu.V., Kutsokon N.K. (2006) Zastosuvannia roslynnykh test-system dlia otsinky kombinovanoi dii faktoriv riznoi pryrody [The use of plant test systems to evaluate the combined effect of factors of different nature]. Kyiv: Fitosotsiotsentr, 60 s. [in Ukrainian]
5. Ekolohichni pasporty Lvivskoi oblasti za 2018–2021 r. [Environmental passports of the Lviv region for 2018–2021.] URL: https://deplv.gov.ua/ekologichnyj-pasport/ (Last accessed: 05.09.2021) [in Ukrainian]
6. Kupchyk O.Yu. (2015) Vykydy avtomobilnoho transportu yak dzherelo zabrudnennia atmosfernoho povitria mista Chernihova [Motor vehicle emissions as a source of atmospheric air pollution in the city of Chernihiv]. Molodyi vchenyi, № 2 (17), S. 17–20. [in Ukrainian]
7. Osyka V.F. (2001) Yakist vymiriuvan skladu ta vlastyvostei obiektiv dovkillia ta dzherel yikh zabrudnennia: monohrafiia [Quality of measurements of composition and properties of environmental objects and sources of their pollution: monograph]. Kyiv: Nauka, 663 s. [in Ukrainian]
8. Prysedskyi Yu.H. (2017) Adaptatsiia roslyn do antropohennykh chynnykiv: pidruchnyk dlia studentiv vyshchyh navchalnyh zakladiv [Adaptation of plants to anthropogenic factors: textbook for higher education students]. Vinnytsia: TOV “Niland-LTD”, 98 s. [in Ukrainian]
9. Rehionalna dopovid pro stan navkolyshnoho pryrodnoho seredovyshcha Lvivskoi oblasti (2018–2020 rr.) [Regional report on the state of the natural environment of the Lviv region (2018–2020)]. Ministerstvo zakhystu dovkillia ta pryrodnykh resursiv Ukrainy. URL: https://menr.gov.ua/ (Last accessed: 04.06.2021) [in Ukrainian]
10. Barabash O., Lozova T., Kozlova T. (2017) Assessment of the urban environment quality in Kyiv. *Acta Carpathica*, № 28. P. 5–12 [in English]
11. Franiel I. (2008) Fluctuating asymmetry of Betula pendula Roth. leaves – an index of environment quality. *Biodiv. Res. Conserv*., Vol. 9–10. P. 7–10. [in English]
12. Hoivanovych N., Pavlyshak Ya., Antonyak H. (2019) Influence of anthropogenic load in the city of Stryi on the functional state of photosynthetic apparatus of plants-indicators. *Acta Carpathica,* № 31–32. P. 52–59 [in English]
13. Velickovi M. (2010) Developmental stability in Tilia cordata leaves. *Period biol*., Vol. 112, № 3. P. 273–281. [in English]