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ORIGINAL ARTICLE

Urban trees assimilation efficiency and assessment of environment quality

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The conception of functional adaptation of woody plants in the changing conditions of natural ecotopes and the urban ecosystem is substantiated. The new integrated methods for estimation of the natural environment transformation under the pressure of urbanization are suggested. The objects of our research are 49 species and forms of woody plants inhabiting the urban ecosystem of Lviv, natural and artificial tree stands of Ukrainian regions. Also, we focused our attention on the anthropotransformation of microclimate, soil changing in tree plantations and problems of edaphotopes contamination. The main subject of the original plant studies were the general phenotypic functional changes in the assimilation apparatus of tree species, which can be estimated by the complex of conventional and new indicators of chemical and biochemical composition of leaf dry matter from ecotopes with different living conditions and origin. We investigated the morphological, physiological and biochemical reactions of assimilating organs of woody plants affecting their growth and development in the conditions of the Lviv city and in the natural conditions of forests and parks. As a result of long-term studies of such reactions, we have suggested an original methodological approach to elucidating the levels of phenotypic functional adaptation. Also, the ability of autochthonous and allochthonous (exotic) tree species to adapt their growth and development to new or modified anthropogenic environment has been studied out. The average level of sugars in the leaves during vegetation was considered as a normal level with the maximum at the beginning, and subsequent decrease in the middle while the minimum of content was determined at the end of the growing season. The appropriate character of starch metabolism are displayed by average levels in different species, with the maximum concentration in July and subsequent minimization of their content at the end of the growing season. The naturally determined dynamics of fiber (cellulose) concentrations implies gradual decline in the period from spring to autumn of its proportion in the leaves dry matter at the high level of concentration, similarly as in the native species. The gradual increase in the proportion of all water-soluble carbohydrates about insoluble in adapted native plants was considered as a natural. A small amount of sugars in a ratio with the general concentration of ash in the leaves at the end of the growing season, we consider as auspicious. Suggested by us clusterization of native and exotic tree species concerning of the efficiency of their introduction in different urban plantations, and depending on the degree of anthropogenic ecotope transformation, allows diversely and effectively recommend different tree species and their forms in varied scopes of application. We used indicators of phenotypic functional adaptation while inventorization of Lviv botanical gardens collections has taken place. The informative criteria for assessing the status of plants, selection of resistant local and introduced individuals with high adaptive potential were elicited by mentioned above indices. A comprehensive approach to the study of ecotope qualities is effective for assessing the acclimatization conditions for tree exotics in the botanical gardens of Western Ukraine and for developing agrotechnical measures for their cultivation.

Key words: Adaptation; Endurance; Ecotope; Nitrogen; Proteins; Carbohydrates; Fats; Fiber; Acclimatization

Introduction

Forest cover of the planet, planting of different functional significance, and even individual trees and shrubs are powerful natural factors of stability of different sizes ecosystems and landscapes in general. These are tools of phytomelioration on destroyed or inadequate natural environment, and leverages of leveling the negative environmental impacts of urbanization and industrial pollution. At the same time, this surrounding environment of trees and bushes affects the living condition of the plants in different ways, sometimes negatively. It limits their productive potential and ameliorative role (Kramer & Kozlovski, 1983; Treshou, 1988; Lutsyshyn & Teslenko, 2015; Livesley et al., 2016; Vishchur et al., 2019).

A presentable example is the problem of Norway spruce (*Picea abies* (L.) H. Karst.), which grows in the Carpathians, as well as other species in different regions. We are seeing a massive shrinkage of spruce forests for several decades. The main cause of this disaster is inadequate soil and climatic conditions to environmental needs of Norway spruce. As a result of the lack of functional adaptation trees, in case of enhanced the impact of adverse external factors (prolonged drought, arid mesoclimate, eutrophication ecotypes, etc.), plant individuals are losing their vitality in consortial, and later on parcel and biogeocenotic ecosystem levels. In this regard, an adequate control that is based on a simple diagnosis of the functional state of woody plants, an assessment of plants efficiency on stabilization of state of the natural or industrial environment by bioindication criteria are important scientific and practical problems of today (Girs, 1982; Schubert, 1988).

Most studies of the impact of the current environment on vegetation plantings have been conducted in cities of other large industrial regions (Treshou, 1988; Korshikov, 1996; Lutsyshyn & Teslenko, 2015; Korshykov et al., 2018). There woody plants undergo significant visible or lethal damage from an excessive pollution. At the same time, only very few observations of auto-ecological plant responses in natural environment, during the process of acclimatization of exotics in the areas of constant exposure to moderate concentrations of pollutants, and in the environment of profound transformation that is common for urban ecosystems.

These conditions usually do not cause a massive visual damage but speed up not only growing but also a full life cycle of trees, causing premature weakening, aging and death of individuals, loss of species and forms diversity of plants and vegetation (Gnativ, 2001).
The scientific outlook on the vitality of woody plants in natural or modified ecosystems on urban cities can be given on the basis of diagnosis of their physiological, functional state and adaptive capacity. However, simple but solid and informative physiological and biochemical, or other criteria for the evaluation of functional adaptation of tree species are still not developed and not used, along with classical biometrics observations of plants` condition. The study of only certain aspects and changes in the metabolism of plants does not answer questions on the functional state of the complex biotic systems – tree or shrub, and the success of its adaptation or acclimatization (McDonnell & Hahs, 2015; Lehostaieva & Berkhmiler, 2018; Boiko et al., 2019).
Clarification of common functional responses of woody species in different ecotypes will encourage to establish more accurately their adaptive capacity and to provide an opportunity to predict the best ways to use them in plantations for various purposes. Lack of overall performance indexes of the integrated responses of a whole organism to growing conditions in the real environment, of its growth and development, is complicating the selection of a stable and promising forestry or a landscape gardening species from indigenous and foreign wood flora. Therefore, work for developing and implementing criteria for the diagnosis of the functional status of woody plants is a key issue of dendroecology, phytomeliorative of urban and industrial landscapes, and the enrichment phytodiversity of forest and decorative plantation (Gnativ, 2001). After all, increased urbanization and potential loss of green vegetative cover including trees and open space in cities may hold important implications for human health (Marsella, 1998; Downey & Van Willigen, 2005; Taylor et al., 2015; Endreny, 2018).
The purpose of our work – to explain the patterns of adaptation of woody plants to natural and urban ecosystems by functional changes in their assimilation apparatus and to describe the decorative species to find out the potential of their usage in forestry for phytomeliorative urban and industrial environment.

Material and Methods

To achieve the main goal, we have made a number of branching and parallel research directions. We have developed a conceptual model for evaluation of the functional adaptation of woody plants in anthropogenic and industrial environments and we have developed and formed a search methodology of new criteria of their condition. The condition of the natural environment was comprehensively described and parametrically estimated in the urban ecosystem of big city (for example, Lviv city). We have analyzed the conditions of introduction and cultivation of plants in the city green area and natural ecotopes of growth of autochthonous breeds. There was made an assessment of morphological and anatomical changes of assimilation apparatus of trees, pigment complex and photo-optical properties of existing leaves in different ecotopes of the city. We have investigated peculiarities of mineral nutrition of woody plants and have clarified the changes of the physical and chemical state of leaves, depending on growth conditions. There were explored changes in the contents and rates in the leaves of woody plants according to main mineral and organic components, depending on the degree of conversion to urban environment in Lviv city and a variety of environmental and geographical conditions of other region in the Western Ukraine. We have compared the dynamics and features of the metabolic changes in leaves of woody species during vegetation in cultural urban plantations and natural plantations. We have found out their importance for the function adaptation of assimilation apparatus during the course of the growing plants strategy of urban ecosystem of the big city. We made a comparison of exotic wood according to the degree of acclimatization and adaptation levels of individuals on the basis of functional changes of an assimilation apparatus in the new environment. We have made assessment of their resistibility and horticultural usefulness in Lviv urban ecosystem. It was tested and proved that functional adaptation index of woody plants are preferable for dendrophysiological quality indication of urboecotopes and industrially polluted environment.
The objects of our research were woody plants (49 species and forms) in urban ecosystem of the Lviv city, natural and artificial tree plantations in different regions in Ukraine, the changes of microclimate and soil transformation in plantations, and pollution of edaphic tops. The main subject of the original research were the overall functional changes in the assimilation apparatus of woody plants by both classic and new indicators of chemical and biochemical content of a dry matter in tree leaves of different properties and origin of ecotops.
The methods of the research (Kramer & Kozlovski, 1983; Schubert, 1988; Treshou, 1988) – biometric, physical and chemical, optical on the morphological and functional state of existing plants; meteorological, agrochemical, spectrographic on the quality ecotops; chemical, spectrophotometric on component composition of phytomass of plants; statistics and graphics using computer modeling.
We are offering a clustering of aboriginal and exotic woody plants for the efficiency of their usage in various urban plantings, depending on the degree of change in ecotops. This allows differentiative and effective implementation of tree species to different areas: forestry and horticulture. The method of visual diagnosis of the condition of trees and shrubs on indicators of mineral nutrition is suitable to use in nurseries and farms in the Western Ukraine in order to increase the proportion of certified planting material. The indicators of functional adaptation were used during inventory of collection funds of botanical gardens of the Lviv city. They proved to be reliable criteria for the assessment of plant condition, selection of the resistant aboriginal and exotic plant individuals with high adaptive capacity. A complex method in the investigation of qualities of ecotops proved to be effective for the evaluation of acclimatization conditions of woody exotic in botanical gardens in the Western Ukraine as well as for the development of agronomic technology.

Results

The functional adaptation of a plant is a restructuring process in the internal state of the phenotype, its structures, and its constant work for selforganization and selfconstruction of an organism within the normal reaction to ensure an effective adaptation of its organ and organismal levels in a changing environment. The result of the functional adaptation, for example of woody plants in each real (natural or anthropogenical transformed) ecotope under insufficient/excessive action of natural essential factors, or the impact of new urbo-, and industrial environment, is a quantitative and qualitative changes in a certain metabolic reactions of separate organs. If the influence of an adverse does not in generally counter exceed in power the adaptive capacity of plants, then the mechanisms of functional adaptation are triggered at the level of the whole organism. As a result of it there is: a change in balance of plastic materials, characteristic for the optimal living conditions, as well as, in the more active formation or consumption of metabolically important compounds, and in the accumulating of relevant for organism energy and mineral elements (Figures 1-4). The most interdependent and expressive indicators of the quantitative and qualitative composition of the leaves have been divided into two categories for each plant species. The first category included the native species that formed experimental group of Normal

Ecological Conditions. The second category included plants, which affected by adverse environmental conditions. In addition, we distinguished between the normal (aboriginal) and negative course of vegetative changes for concentrations and the ratio of metabolites in the leaves. We assigned the 10 points to parameters, which were recognized as normal, accordingly to parameters for adverse conditions – 0 points were assigned. The average level of sugars in the leaves during vegetation was considered as a normal level with the maximum at the beginning, and subsequent decrease in the middle while the minimum of content was determined at the end of the growing season (Table 1).

The appropriate character of starch metabolism are displayed by average among levels in different species, with the maximum concentration in July and subsequent minimization of their content at the end of the growing season. The favorable dynamics of fiber (cellulose) concentrations implies a gradual decline in the period from spring to autumn of its proportion in the leaves dry matter at the high level of concentration, similarly as in the native species. It was considered as a natural the gradual increase in the proportion of all water-soluble carbohydrates about insoluble in adapted native plants.

A small amount of sugars in a ratio with the general concentration of ash in the leaves at the end of the growing season, we consider as auspicious. It was ascertained that despite of the possible whims of the weather, during the growing season, the plants have an appropriate level of the carbohydrate metabolism.

Table 1. Functional criteria characterizing the adaptation of woody plants according to the most representative quantitative and dynamic indicators of the assimilation apparatus reaction to the growing conditions.

Indicators of leaves metabolic processes	**criteria**	
	Normal range and level at critical period	**Normal range and level during the growing season**
The content of reducing sugars in the phase of the active growth of leaves and shoots (May-June), % in dry weight	5–10	From the largest at the beginning to the smallest at the end
Starch content during the most active period of assimilation (July), % in dry weight	1.5–3.0	From average at the beginning to the highest at mid-melon and minimum at the end
The fiber (cellulose) content of the most active assimilation period (July), % in dry weight	12–22	From the highest proportion at the beginning to the lowest at the end
The ratio of the amount of nitrogen free extractive (NFE) to the total amount of cellulose and lipids (index of water-soluble carbohydrates) in the most active period of assimilation (July), relative units	1.2–1.8	From the minimum at the beginning to the maximum at the end
Ratio of sugar content to the total ash content in the most active assimilation period (July), relative units	1.0–2.0	From the maximum at the beginning to the minimum at the end
Elemental nutrition balance index (ratio of ash to total nitrogen – July), relative units	1.0–2.0	From the minimum at the beginning to the maximum at the end
Mineral nutrition efficiency index (ratio of carbohydrate to total nitrogen and ash elements – July), relative units	6.0–9.0	From the maximum at the beginning to the minimum at the end

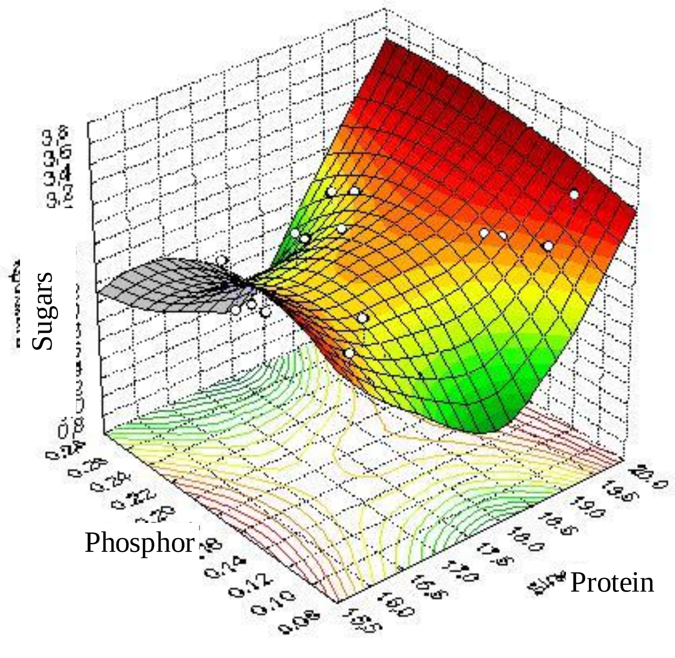

Figure 1. The reservations of starch, depending on the phosphorus content and protein synthesis in the leaves of oak planting, % of dry matter.

The evolutionary result of the functional adaptation is a consolidation of the adapted phenotypes and the transfer to the offspring of "metabolic memory" about previous problems, and the formation and localization of the new ecotypes (races, varieties, etc.) (Hnativ, 2014).

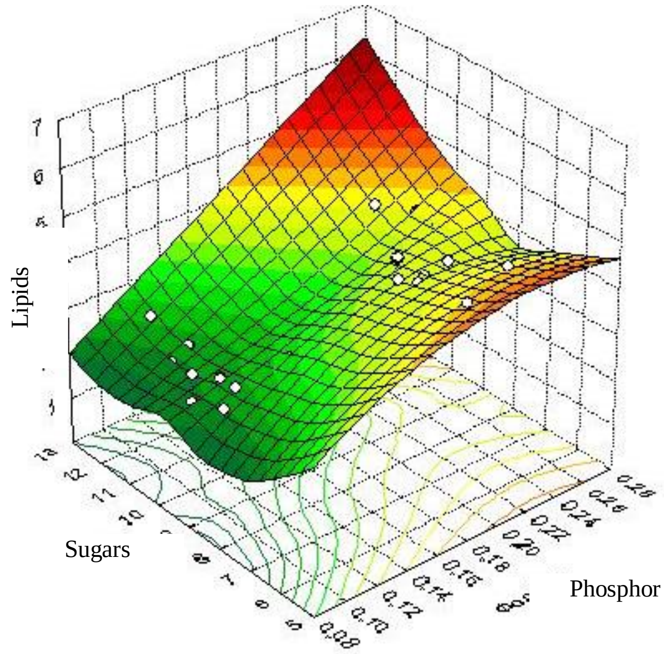

Figure 2. The formation of lipids due to sugar and phosphorus content in the leaves of oak planting, % of dry matter.

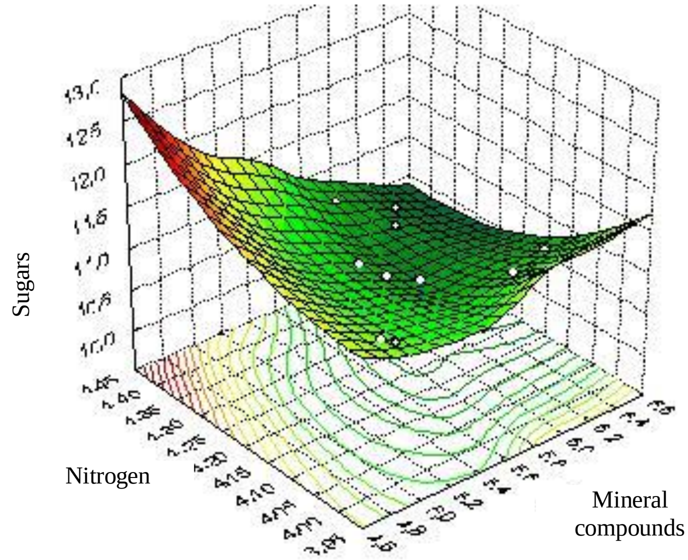

Figure 3. The changes of content on renewable of sugars in the leaves of beech, depending on the level of mineral compounds and nitrogen assimilation on the middle of the warm season in street plantations, % of dry matter.

Functional adaptation happens also when certain plant organs, such as leaves, are damaged from the effects of adverse factors, but the overall growth and development of woody plants is not terminated, or inhibited only at certain stages of ontogeny in individual phases of development or in some vegetation periods that generally do not affect the implementation of the strategy phenotype. That is why functional adaptive changes as a result of work of the entire organism, not individual metabolic reactions or triggering of certain internal systems can be identified and characterized in quantitative parameters and by ratios of plastic substances in the organs of plants, particularly in the leaves. It is important to establish the most active metabolic levels and cumulative changes that occur in the assimilation system. For proper scientific study they can be used as general indicators of functional adaptation of woody plants (Hnativ, 2014).

Discussion

Functional adaptation metrics over the specified algorithm laboratory analysis has wide application (Figure 5). If there were made an in-depth studies of functional changes in the assimilation system of Norway spruce (*Picea abies* (L.) H. Karst.) (Shparyk, 2017) or European pine (*Abies alba* Mill) (Pogribnyy et al., 2018) at macro-metabolic level (total and protein nitrogen, soluble carbohydrates, and fatlike polymerized, mineral nutrients, pollution, etc. – Figure 5) as well as other functional indicators, and also to assess comprehensively the adequacy or dynamic changes in the quality of ecotypes spruce plantation (by indicators of microclimate, nutrition, and edaphotopes humidity etc.) we would be able to get an undoubtedly reasoned answer to the question: why certain plant, the whole parcels or even the whole biogeocoenoses are drying up? Systems approach to vision of mutual influence of an environment and a plant has a double sided result (Abis & Brovkin, 2017; Zhao et al., 2017). An objective parameter estimation of the influence of an environment on the functional performance of the assimilation apparatus of tree species is always a mirror to the qualitative state of the environment (Yang et al., 2017), and therefore is a perspective for biological indication of the urban environment (Hnativ, 2014; Pretzsch et al., 2017).

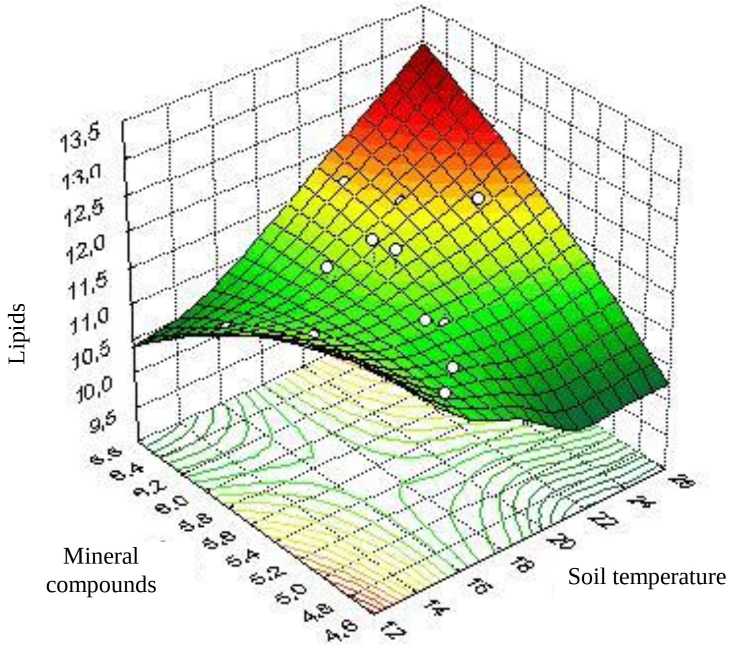

Figure 4. The synthesis of lipid in beech leaves, depending on the accumulation of mineral elements and soil temperature (°C) on the middle of the warm season in street plantations, % in dry matter.

Trees, and initially their assimilation apparatus, are always quick to respond to negative changes in growth environment parameters. Such changes are early signals of air pollution, acidification or alkalisation of soils, climate aridization, general environmental degradation for plants and humans. Based on the response of woody plants and their assimilation apparatus, decisions must be made on how to improve the quality of the plant growth environment and human life.

Beech (*Fagus sylvatica* L.), oak (*Quercus rubra* L.), maple (*Acer platanoides* L.), lime *Tilia cordata* Mill), birch hanging (*Betula pendula* Youngii), white willow (*Salix alba* L.) and other autochthonous species in Western Ukraine accurately reflect the condition of the environment in local landscapes in the spectra of the chemical composition of their leaves. These spectra reflect atmospheric chemical, general urban or specific soil pollution in profound environmental transformation completely adequate (Gnativ, 2001).

Maintaining functional durability and phytodiversity, of trees and shrubs that were planted until now, as well as the expansion of the range of ornamental species for landscaping by both local and exotic plants in order to preserve their culture, is the most urgent problem of improving the conditions of the urban environment and effective cost spending on improvements in the residential areas (De Vries et al., 2013; Hartig & Kahn, 2016). They can be solved by introducing a differentiated system of care, depending on the conditions of life, age, species` outecologycal features and the degree of viability of ornamental crops.

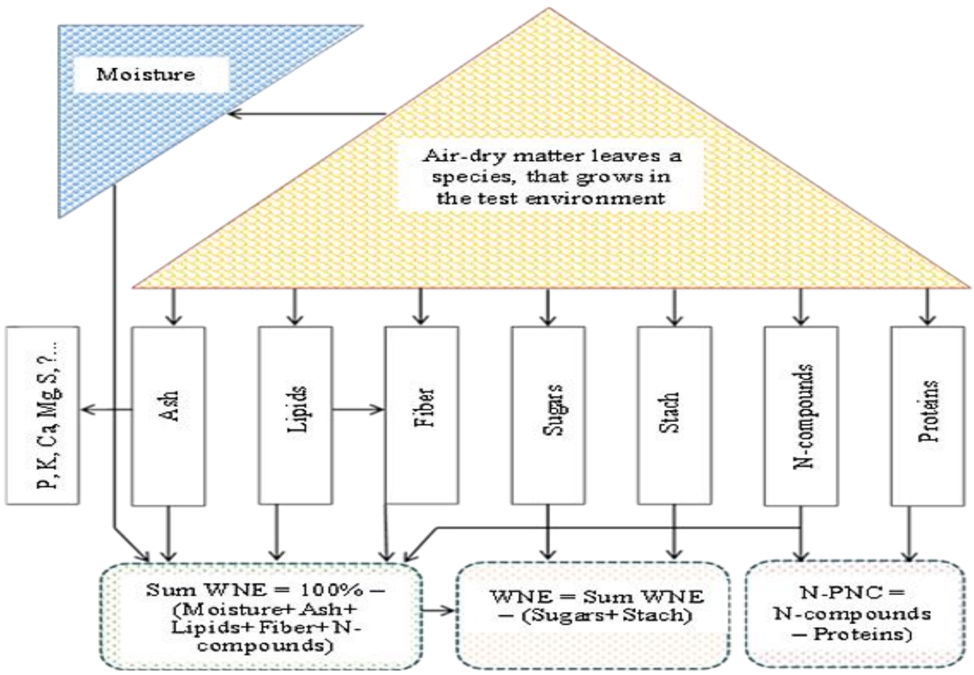

Figure 5. Algorithmic analysis of woody plants adaptive functional responses to changing conditions of cultivation (N-compounds – nitrogen-containing compounds, WNE – without nitrogenous extracts, N-PNC – non-protein nitrogenous compounds).

Introduced, acclimatized and, in many cases naturalized, exotic trees (*Aesculus hippocastanum* L., *Cercidiphyllum japonicum* Siebold & Zucc. and other) provide a viable seeds and form the new ecotypes (Hnativ, 2014). They can serve as undervalued objects of the new out-ecological, genetic and evolutionary scientific information. They are the source of seed and vegetative mutant breeding material. Indicators of assimilation by woody plants of elements of nutrition, synthesis of proteins, sugars, formation of fiber and lipids allow to distinguish genotypic mutations from phenotypic variability (Bergmann, 1986) and without genetic analysis to identify garden ornamental forms by the color of the leaf apparatus.

Conclusion

Basing on the research and conclusion of the functional adaptation of woody plants in the new growth conditions, it is possible to start a breeding work for the introduction of exotic species and forms in ornamental horticulture, phytomelioration and forestry. However, in our days it is difficult to develop such a system of care within an urban green spaces, and widespread adoption of exotics, due to the lack of sufficient knowledge, and, therefore, lack of understanding of the functional adaptation of trees to the inadvertently or deliberately formed new conditions of anthropogenical environment. We supposed that ability to identify internal and external functional adaptation of trees towards transformed anthropogenic environment will only ensure the success of plant cultivation, phytodiversity conservation and longevity.

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