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THE INFLUENCE OF URBAN ENVIRONMENT FACTORS ON THE GROWTH OF HORSE CHESTNUT *AESCULUS HIPPOCASTANUM* L.

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ABSTRACT

Aim of the study
In the years 1995–1999, at 21 sites within the broadly understood center of Poznań, research on the development of chestnut *Aesculus hippocastanum* L. was carried out. As part of this research, selected environmental factors were analysed. The aim was to become familiar with the conditions of tree development in the urban and industrial agglomeration of Poznań.

Material and methods
Knowledge of tree development limiting factors in urban conditions allows to take actions that will eliminate them or limit their negative impact on the development of trees, including their biometric parameters. The implementation of such actions will neutralise or compensate for undesirable processes in the urban environment. As a consequence, it will allow for unlimited environment-generating functions by trees such as: CO_2 assimilation, oxygen release, water vapour transpiration, dust retention, phytoncide production or noise suppression.

Results and conclusions
Research on the development of 35 chestnut trees at 21 streets included: seasonal periodicity of trees, recording air temperature and humidity, physico-chemical analysis of the substrate, biometric measurements and, at eight sites, selected physiological parameters, such as photosynthesis and transpiration. In total, over 17,000 numerical data about the environment were collected. The graphs in this paper present mainly the relationship between environmental parameters and biometric measurements at a highly significant level in terms of statistics, i.e. for $p \leq 0.01$.

Key words: *Aesculus hippocastanum* L., city ecology, biometric measurements

INTRODUCTION

Urban and industrial agglomerations typically constitute a mosaic of habitats where deteriorating living conditions for plants prevail, generally, along the environmental transect, from the outskirts to the city centre. The escalating degradation of the environment consists mainly in its advanced xerism and toxification (Zimny, 1973). In city centres, this translates into the existence of a set of abiotic factors of the stony desert type, not naturally found in our latitudes. This, in turn, directly affects the development prospects and the course of the most important life functions of trees (S. Łukasiewicz and Oleksyn, 2007).

The general trends towards progressing xerism and toxicity in cities is overlapped by alterations in topographical, climatic and substrate conditions, as well as changes in soils, vegetation, fauna, etc. The greatest

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intensity of these changes concerns intensively built-up agglomeration centres, where the scale of anthropogenic pressure negatively impacts the human living environment, causing its degradation (Landsberg, 1981; Blume, 1989; Bartkowski, 1991, Bullock and Gregory, 1991; Wittig, 1991; Schleuss et al., 1998).

Difficulties in environmental studies of cities are also compounded by altered and accidental relationships of elements in soils. The disturbed physicochemical composition means that most of the correlations between the elements, which are described in soil science textbooks, in fact do not occur in urban soils. Subsequently, this results in the lack or statistically insignificant correlations of the content of elements in the substrates with their percentage share in the leaves, physiological processes, and environmental parameters.

Studying the numerous interactions between plants and the complex of urban conditions is notoriously difficult, because it should involve interdisciplinary, long-term, and therefore expensive research effort. Hence, the study of urban ecology, despite the fact that it opens up a broad range of research opportunities, remains a scientific challenge for future generations, and terming urban ecosystems "untapped opportunities in ecology" is still valid (McDonnell and Pickett, 1990).

MATERIAL AND METHODS

In the years 1995–1999, in designated sites along 21 streets within the centre of Poznań (broadly understood), research was conducted into the development of the common (white) horse chestnut *Aesculus hippocastanum* L. (Fig. 1). The reference site – the point of reference for the study – was a stand of trees growing in the Adam Mickiewicz University Botanical Garden in Poznań. As part of these studies, analyses of selected environmental factors were conducted. The aim of the study was to learn about the conditions for the development of trees in the urban-industrial agglomeration of Poznań. The horse chestnut was selected as a species that turned out to be highly sensitive to urban conditions, and thus reacting quickly to unfavourable changes in the environment. This solution made it possible to accurately assess the relationship between environmental causes and their effects in the form of abnormal tree development. Studies into the development of chestnut trees at all sites included: seasonal rhythmicity of trees, recording temperature and air humidity at individual sites, physicochemical analyses of the substrate, biometric measurements and chemical composition of leaves, as well as – at eight sites – examining selected physiological parameters such as intensity of photosynthesis and transpiration. The paper addresses those correlations, which proved statistically significant at $p \leq 0.05$. Majority of the dependencies presented in the graphs show the correlations between environmental parameters and biometric measurements at a highly statistically significant level, that is, for $p \leq 0.01$.

A full description of the working methods can be found in S. Łukasiewicz's work (2002) and in the author's thematic articles on his homepage: http://stasim.home.amu.edu.pl/materia%C5%82y-do-pobrania;

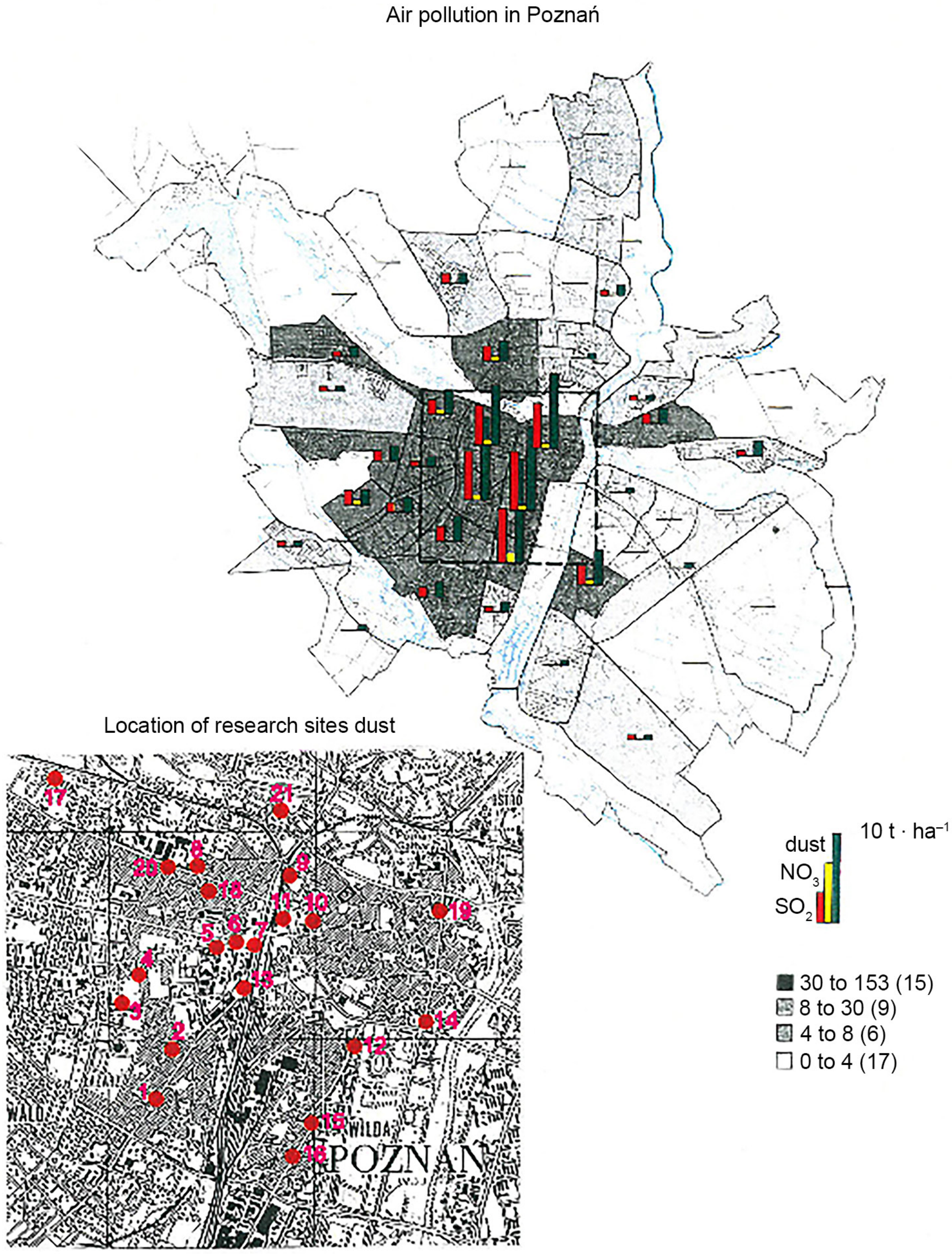
Oleksyn et al., 2007: http://stasim.home.amu.edu.pl/images/publikacje/Ecophysiology_of_horse_chestnut_(Aesculus%20hippocastanum-L.).pdf;

S. Łukasiewicz, Oleksyn, 2012: http://stasim.home.amu.edu.pl/images/publikacje/Rekompensujacy_wplyw_wolnej_nieutwardzonej_powierzchni_gleby.pdf;

S. Łukasiewicz, 2012a: http://stasim.home.amu.edu.pl/images/publikacje/Struktura_fizyczna_gruntu_zawarto%C5%9B%C4%87_substancji_organicznej-Cz-III.pdf;

S. Łukasiewicz, Oleksyn, 2007: http://stasim.home.amu.edu.pl/images/publikacje/Zr%C3%B3%C5%BCnicowanie_przestrzenne_element%C3%B3w_meteorologicznych.pdf

Chemical analyses of the available forms of 16 macro- and microelements, including N (NH4 + NO3), P, K, Ca, Mg, S (SO4), Fe, Mn, Zn, Cu, B, Cl, as well as sodium, lead, and cadmium, were conducted according to the universal method (modified Spurway-Lawton method), proposed by Nowosielski (Nowosielski, 1974, 1978; IUNG, 1983; Breś et al., 2003), in air-dry soil. The analyses were carried out at the Department of Plant Nutrition of the Poznań University of Life Sciences. Soil samples were collected in four 30 cm layers. Due to the random formation of soil layers in urban areas, in order to avoid errors in collecting the sample material, two profiles were drilled at each tree, whose corresponding layers were mixed with each other. Thus, a total of four samples were generated for



Ryc. 1. Rozmieszczenie 21 stanowisk badawczych kasztanowca zwyczajnego (białego) *Aesculus hippocastanum* L. na terenie Poznania, na tle obciążenia powietrza emisją zanieczyszczeń w przeliczeniu na tzw. emisję równoważną (za: S. Łukasiewicz 2002 i cyt. tam lit.). U dołu lokalizacja stanowisk badawczych na tle powiększonego fragmentu mapy topograficznej miasta. Cyfry oznaczają numerację stanowisk.

Fig. 1. The distribution of 21 research sites of the horse chestnut *Aesculus hippocastanum* L. in Poznań, against the equivalent emission of air pollutants (after: S. Łukasiewicz 2002 and quoted therein). Below, on an enlarged fragment of the topographic map of the city, the location of the research sites is marked by their respective numbers.

each tree, every 30 cm, to a depth of 1.20 m. These were collected at a distance of approximately 1.0 m from the tree trunk, due to the concrete and/or asphalt surface surrounding most of the studied trees (the so-called soil basins around the trees, on the edge of the sidewalk and the road).

The content of P, K, Ca, Mg, Mn, Fe, Cu, Zn, Al, B, Pb, Ni, Cr and Cd in leaves was analysed using the ICP--AES spectrometer (model ARL 3560) at the Research Analytical Laboratory at the University of Minnesota (St. Paul, USA, http://ral.coafes.umn.edu/). Chemical analyses of leaves concerned trees from eight sites located at the following streets: Aleja Wielkopolska – 21, Bema – 14, Dominikańska – 19, Grunwaldzka – 7, Matejki – 2, Noskowskiego – 9, Wojskowa – 3, as well as in the Botanical Garden – 17 (Tab. 1–2).

Gas exchange of horse chestnut leaves was measured using a portable infrared CO_2 analyser (LCA-3, Analytical Development Corporation Hoddesdon, England) operating in an open system. Net photosynthesis was measured using previously described methods (Oleksyn et al., 2000) on uncut leaves in field conditions using Parkinson's PLC-B leaf cuvettes.

Biometric tests, seasonal plant rhythms, and soil chemical analyses were carried out at 21 sites. Leaf surface area measurements were made using a ScanJet 6100CT scanner using the WinNeedle computer software (version 3.5, Regent Instruments INC., Quebec, Canada). After drying, they were weighed (using balance type BP 210 S Sartorius, Göttingen, Germany; measurement accuracy up to 0.0001g).

Measurements of annual increments (shoot length and thickness) were made in September 1997. The shoots (3 from each tree) were cut using shears mounted on a telescopic boom, from a height of about 5 meters, off the outer part of the crown. The length of the increments was determined with an accuracy down to 1 mm. Since one-year-old chestnut shoots in cross-section do not form a circle, in order to determine shoot thickness, two measurements were made, recording the average result with accuracy down to 0.1 mm. The shoots were measured at the mid-length of the youngest increment, using a caliper. The circumference of the trunk was measured twice – in 1997 and 2000, at a height of 1.3 meters above the ground, with the accuracy down to 1 cm.

The crown radius was measured in 1997 with an accuracy down to 10 cm. Measurements were made at a distance of $2r$ (r being the crown radius) from the tree trunk.

Tree height was measured in 2000 using the "Sunnto" altimeter (Suunto OY, Vantaa, Finland), employed in forestry.

Research into the seasonal rhythms of plants was conducted based on the methodology of phenological observation (A. Łukasiewicz, 1984).

For air temperature and humidity measurements, in March 1999, micro-recorders of temperature and air humidity were installed at each of the 21 stations (Fig. 1, Onset Computer Corporation, USA). The measurements were conducted from March 10 to December 12, 1999.

Statistical analysis of the results was carried out using the statistical software JMP 12.0.1 for Windows, SAS Institute Inc. The presentation of the results was based mainly on the graphical presentation of the correlations between the examined features/parameters and the determination of the regression equations along with the values of the coefficients of determination (r^2) and their significance level (p), as well as the table with the correlation significance levels. The levels determined on the basis of the significance of the r-Pearson linear correlation coefficients concerned a maximum of n = 35 trees.

The goal of our study was to present the environmental conditions for the existence of trees in the urban agglomeration, including the factors that limit their development. Correlations of numerically expressed environmental features and biometric measurements made it possible to indicate parameters that statistically significantly correlate with the annual increments of trees.

RESULTS AND DISCUSSION

The soil environment of the agglomeration is an anthropogenic substrate, created over several hundred years of the city's existence. As a result, the system of the resulting soil covers is characterized by, among others: unnatural chemical composition, unusual physical structure of the soil, and the absence or residual amount of humus. Sealing of the ground with an artificial surface, typically coupled with high albedo values and the lowering of the groundwater table, create a stone desert-type environment in downtown areas, unheard of in natural state in our climatic zones. Despite such great diversity, degraded areas of large urban and industrial agglomerations share numerous common features, such as: air pollution, the existence of "urban heat islands", where the average daily temperatures and their amplitudes differ significantly (up to several degrees Celsius) from non-urbanized areas, disturbances in water relations, in element circulation, etc. (Bornstein, 1968; Zimny, 1973; Douglas, 1983; Moll and Ebenreck, 1989; Hodge, 1995; Bredshaw et al., 1996; Miller, 1996; S. Łukasiewicz and Oleksyn, 2007; S. Łukasiewicz, 2012a, b).

Correlations of biometric measurements and soil chemical composition

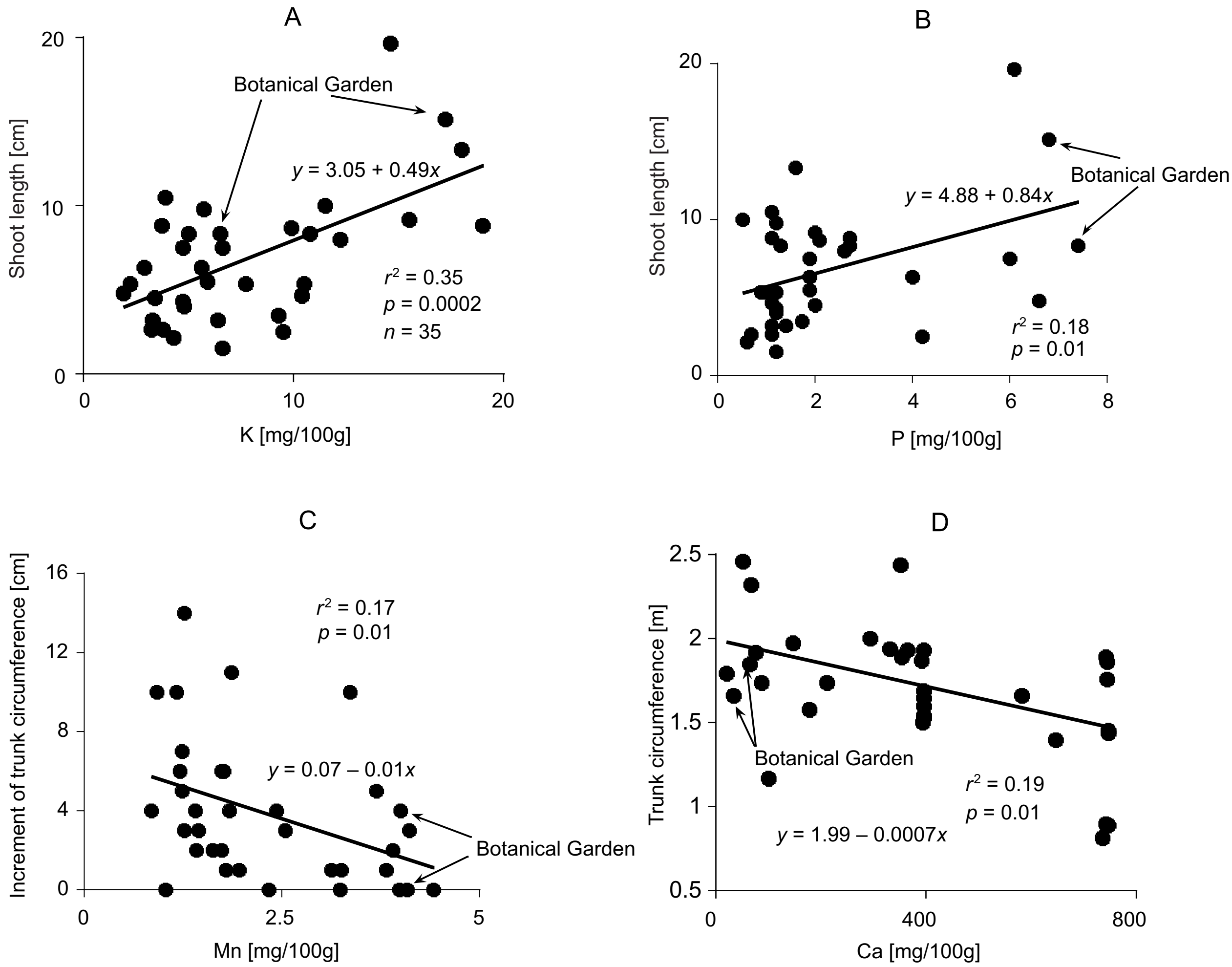
In the surface layer of the soil, that is soil at the depth of 0–30 cm, out of 16 analysed forms of active elements: N ($NH_4 + NO_3$), P, K, Ca, Mg, S (SO_4), Fe, Mn, Zn, Cu, B, Cl, Na, Pb, and Cd, correlations of only two of these elements with biometric features occur at a highly statistically significant level of $p \leq 0.01$. Positive correlations of the length of one-year shoot increments were noted for the content of potassium and phosphorus in the soil (Fig. 2A, B). Negative relationships were noted when analysing the size of trunk increments with manganese content (Fig. 2C) and, in the 90–120 cm layer, trunk circumference increment with calcium ion content in the soil (Fig. 2D).

Correlations of potassium in the soil with shoot increments are consistent with literature data (Mocek et al., 2015). These correlations may result from the relatively high content of this element in the substrate, and the lack of significant antagonistic relationships that would prevent its uptake. The positive correlation of the length of the shoot on the content of phosphorus in the substrate may, as it seems, result from an extremely low level of this macro-element in the substrate, which is additionally blocked by antagonistic reactions, and the precipitation of phosphorous with calcium ions. Negative correlations of trunk increments relative to the content of manganese in the substrate may be the result of a narrowed Fe : Mn ratio of 1.5 : 1, compared to the optimal ratio (2–4): 1 as suggested in the subject literature. The negative impact of manganese in the substrate may be the result of anthropogenic character of urban soils and, additionally, activation of its anionic forms in slightly alkaline soils (Kabata-Pendias and Pendias, 1999). In the oligotrophic soil environment in the city, excessive content of available forms of manganese may cause toxic effects of this microelement on plant development.

A negative correlation was determined between the content of calcium ions in the substrate and the size of tree trunk circumferences (Fig. 2D). A highly statistically significant correlation for the level of 90–120 cm may indicate the accumulative nature of the soil at this depth. A ten-to-twenty-fold over-supply of calcium ions in the soil substrate within cities, compared to unchanged soils, has significant negative consequences for the development of trees. This applies to processes such as alkalization of the substrate and increase in pH, change in the composition of microorganisms, namely, the elimination of fungi, including a change in the type of mycorrhiza, stimulation of bacterial growth, antagonism or mutual blocking of elements expressed by negative correlations of calcium ions with the ions of phosphorus, magnesium, iron, or boron. Unnaturally high levels of calcium can be included among the main diagnostic features of soils in urbanized environments (S. Łukasiewicz, 2012a, b).

Correlations of biometric measurements with the chemical composition of leaves

When analysing the results of measurements of the content of macro- and microelements in chestnut leaves, an unexpected difficulty was encountered. Specifically, it turned out that the chemical composition of *A. hippocastanum* leaves had very rarely been analysed in the past. Out of about 700 papers on this species that had been published since the late 1930s (data from Forestry Abstracts), up to the year 2000, that is, until the mass-scale appearance of the horse-chestnut leaf miner *Cameraria ohridella* causing defoliation and a potential change in the chemical composition of the leaves, only one paper (Guha and Mitchell, 1966) lends itself to comparison. However, it does not contain data for nitrogen. Therefore, when comparing the results, it was necessary to relate them to the data from the Botanical Garden as well as to data for other species of deciduous trees available in the publications. In the pertinent literature, it is noted that the harvest date coincided with the height of summer, that is, the month



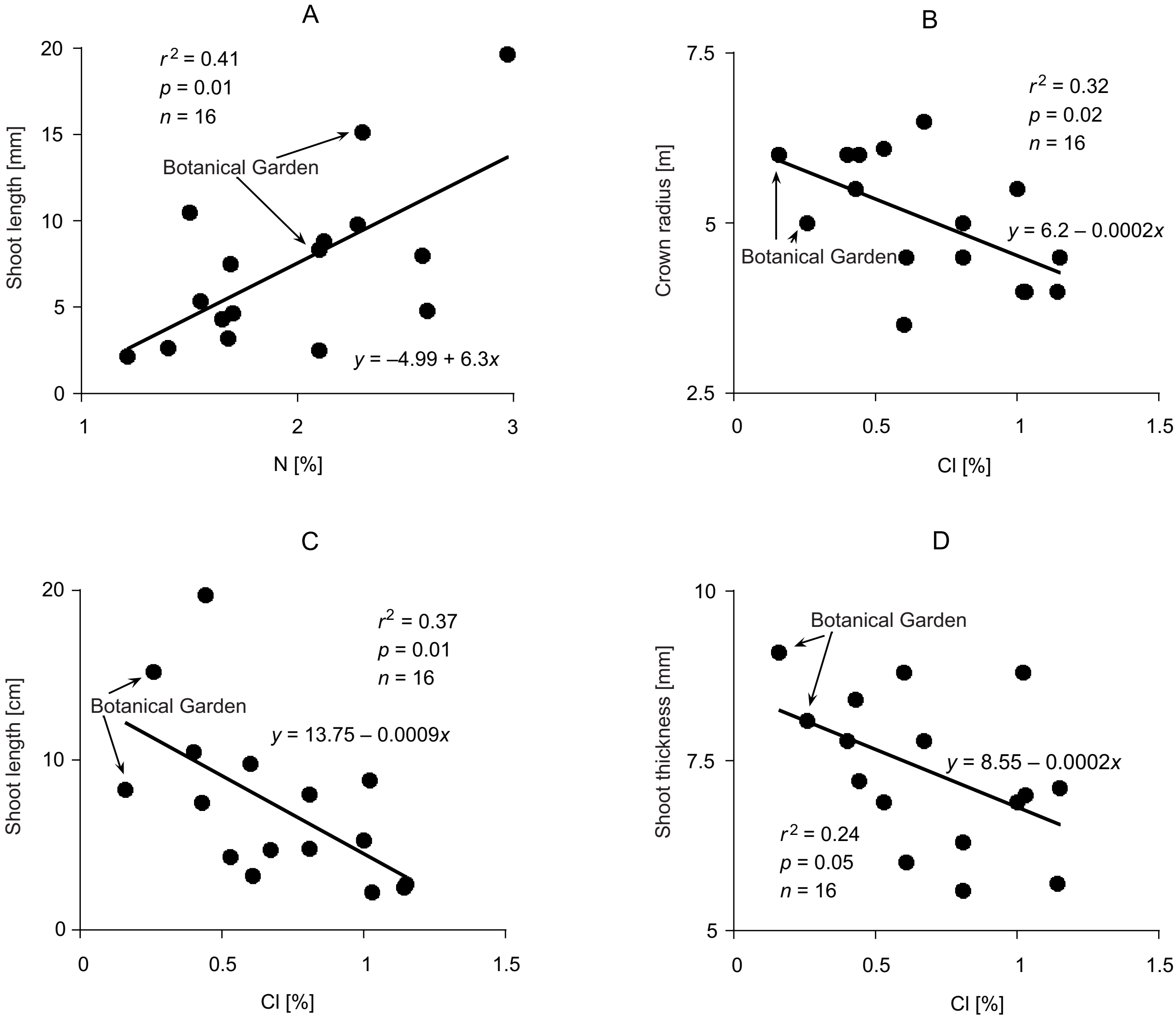
Ryc. 2. Zależność między długością jednorocznych przyrostów pędów kasztanowca zwyczajnego *Aesculus hippocastanum* L. a zawartością potasu (A, 0–30 cm) i fosforu (B, 0–30 cm) w podłożu, między przyrostem obwodu pni drzew a zawartością manganu (C, 30–60 cm) oraz między obwodem pni a zawartością jonów wapnia w glebie (D, 90–120 cm) (Źródło: opracowanie własne)

Fig. 2. Correlations between the annual increments of shoots of chestnut *Aesculus hippocastanum* L. versus the content of potassium (A, 0–30 cm) and phosphorus (B, 0–30 cm) in the substrate; between the growth of tree trunks versus the content of manganese (C, 30–60 cm); and between the trunk circumference versus the content of calcium ions in soil (D, 90–120 cm) (Source: own elaboration)

of August, and the leaves were collected from healthy individuals, from sites that fostered and ensured their proper development (Guha and Mitchel, 1966; Fober, 1990, 1993, 1995, 1999). The data presented in the aforementioned publications point to the existence of significant differences between the content of individual components in chestnut trees in Poznań versus the results recorded for other types of deciduous trees (S. Łukasiewicz, 2002).

The average content of nitrogen, the main plant nutrient, was shown to be lower than its value in all types of deciduous trees, including chestnut leaves from the area of Warsaw (Molski et al., 1976). The average content of N in chestnut leaves from the area of Poznań (1.96%) was determined to be nearly a quarter lower than the values found in other deciduous trees. These data confirm the low level of this macro-element, recorded in the analyses of substrates in sites with *A. hippocastanum* within the city of Poznań. At the same time, they indicate that nitrogen deficit may be one of the main factors limiting the development of trees in the urban environment. In addition to causing lower biometric increments of wood and leaf surface, the insufficient supply of plants with this element can also result in a decrease in the intensity of CO_2 assimilation. This is due to the fact that about 50% of the nitrogen contained in the leaves participates directly in the photo- and biochemical processes of CO_2 assimilation (Mooney, 1986).

Fig. 3A shows the correlation between the size of the increments of one-year-old shoots and the percentage share of nitrogen in the leaves. This correlation



Ryc. 3. Zależności: długości jednorocznych przyrostów pędów kasztanowca zwyczajnego *Aesculus hippocastanum* L. od procentowej zawartości azotu w liściach (A) oraz promienia korony (B), długości (C) oraz grubości pędu (D) od procentowej zawartości chloru w liściach (Źródło: opracowanie własne)

Fig. 3. Correlations between the annual increments of the shoots of chestnut *Aesculus hippocastanum* L. versus percentage content of nitrogen in leaves (A); and between crown radius (B), shoot length (C), and shoot thickness (D) versus percentage content of chlorine in leaves (Source: own elaboration)

occurs at a highly statistically significant level. Such marked dependence is worth emphasizing due to the fact that there are highly statistically significant differences in the nitrogen content in leaves between the sites. The statistical significance of the coefficient of determination for 16 trees growing along 8 streets in the studied area is $p = 0.01$ with $r^2 = 0.41$.

A characteristic feature of the urbanized environment is contamination of the soil with chlorine as a result of the wintertime treatment of sprinkling the roads with NaCl. Together with the transpiration current, the latter compound enters the green parts of the plants. As a result, an increase in the percentage of Cl content in the dry matter of leaves is observed. The content of this element in leaves, in unchanged conditions, oscillates around 0.01%, hence it is classified as a micronutrient (Gliński, 1999; Gorlach and Mazur, 2002; Starck, 2002). In the studies here reported, the content of Cl in the leaves exceeded even 1%. This means over 100-fold (!) excess in its percentage share compared to leaves from non-urban habitats. Figures 3B–D, show the negative correlations of chlorine content with biometric measurements, specifically, the crown radius (Fig. 3B) and shoot length and thickness (Fig. 3C–D). These correlations demonstrate the negative impact of chlorine in urban soils on the physiological processes of plants. It is expressed in a decrease in the increments and thickness of shoots and, consequently, also in the size of the tree crown. This fully justifies the view that an elevated level of chlorine is one of the main causes of tree decline in cities (Marschner, 1995; S. Łukasiewicz, 2002, 2012b).

Correlations of environmental factors with biometric measurements

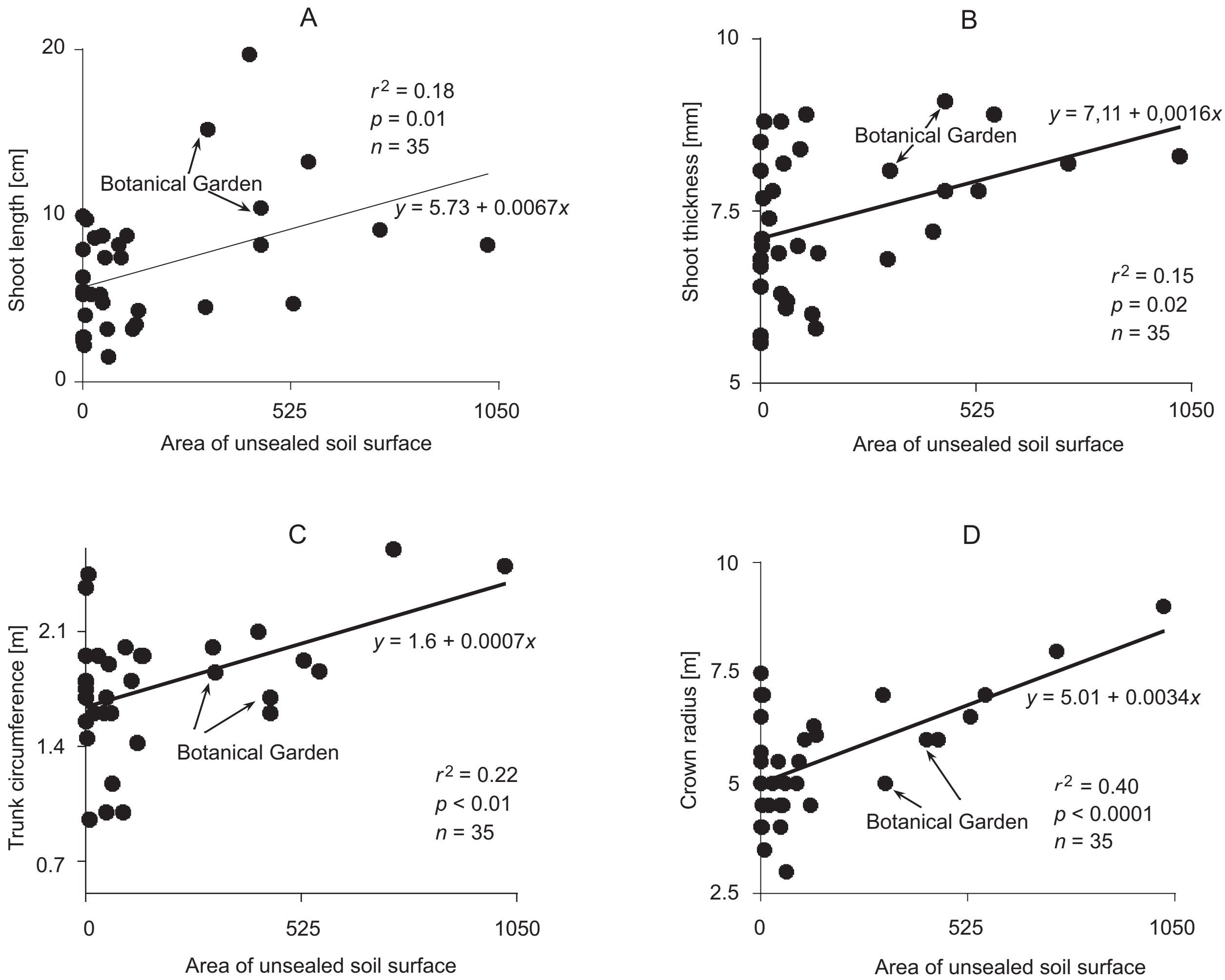
According to the data from the available subject literature, the size of the free, unpaved and unsealed soil around trees has a decisive influence on their proper development in the urbanized human environment. Sufficiently large, that is $\geq 10\ m^2$, unpaved and unsealed area under the tree crowns turned out to be a factor that compensates for the negative impact of urban conditions – the factor, which in fact directly affects a number of environmental parameters. The latter include: differences in average temperatures, air humidity, and air humidity deficiency, as well as the intensity of transpiration (S. Łukasiewicz and Oleksyn, 2012). In addition to the factors mentioned above, positive correlations of the size of unpaved soil occur with a number of biometric parameters: shoot length and thickness, trunk circumference, and tree crown radius (Fig. 4A–D). This proves the positive, beneficial effect of the free, unpaved and permeable surface around the trees on the complex of environmental factors, physiological and biometric parameters and, consequently, on the proper functioning of trees in the urban environment.

Correlations of phenological phases with biometric measurements

In the study of the seasonal rhythms of plants, the length of successive phases of their development is defined in terms of the total number of days. The foliage phase covers the lifetime of healthy, photosynthetically active leaves until its end in the fall. The undisturbed functioning of green leaves on trees from April through September means a longer photosynthesis process, i.e. the production of more assimilates. The uninterrupted supply of assimilates until the end of summer results in a larger pool of substance reserves at the beginning of the next growing season. This directly affects the dynamics of the spring development of plants, both above- and below-ground. That in turn leads to greater biometric increments, specifically greater length and thickness of the shoot, as evidenced in Fig. 5A–B.

Correlations of physiological processes with biometric measurements

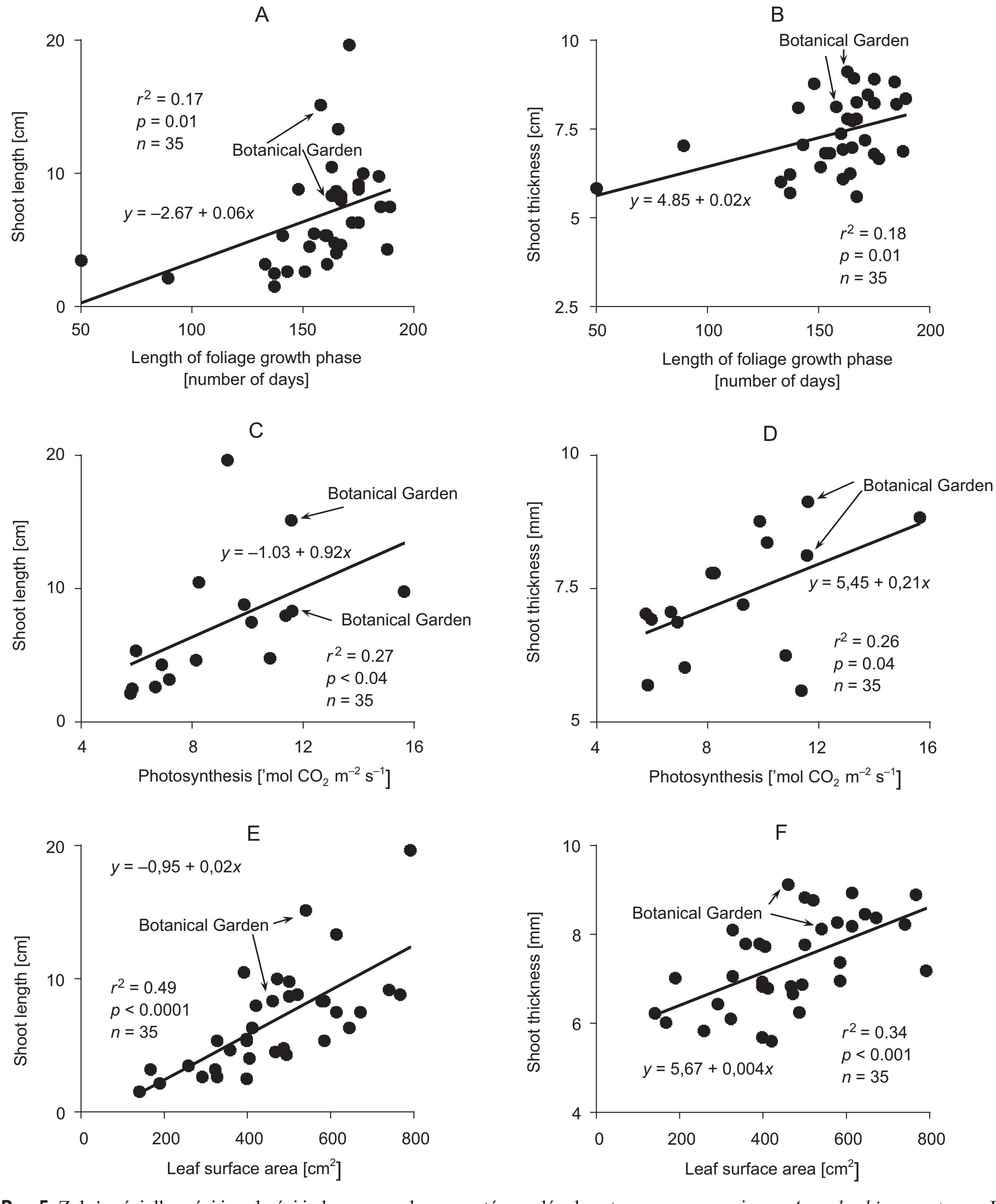
Photosynthesis is the main process that determines the life of organisms on Earth as we know it today. The ability to produce chlorophyll, the intensity of CO_2 assimilation, and of oxygen release, as well as water transpiration – all these are directly dependent on the extent of urban space degradation. For plants, the latter is mainly expressed in the quality of the soil environment measured by the humidity of the substrate, in the availability of mineral nutrition for trees, and in the changes of atmospheric parameters, mainly temperature and humidity (S. Łukasiewicz and Oleksyn, 2007, S. Łukasiewicz, 2012a, b). The correlations of photosynthesis intensity with the size of annual increments and the thickness of shoots obtained in the urban environment fully confirm this correlation (Fig. 5C–D), and illustrate the significant impact of photosynthesis rate on the growth and development of trees.



Ryc. 4. Wpływ wolnej, nieutwardzonej powierzchni gleby na długości (A) i grubości (B) jednorocznych przyrostów pędów oraz na obwód pnia (C) i promień korony (D). Dane dla 35 drzew kasztanowca zwyczajnego *Aesculus hippocastanum* L. na terenie Poznania (Źródło: opracowanie własne)

Fig. 4. Impact of the size of unsealed, unpaved soil surface on the length (A) and thickness (B) of annual shoots, on the trunk circumference (C), and crown radius (D). Data for 35 trees of chestnut *Aesculus hippocastanum* L. species in Poznań (Source: own elaboration)

The formation of healthy, fully developed leaves is the result of compounded environmental factors, whereas lush and abundant foliage is an indication of favourable conditions existing for plant development. In such conditions, the results in increased shoot length and thickness, compared to sites with unfavourable environmental conditions (Fig. 5E–F, Tab. 1–2.). The correlations presented in the graphs are at a highly statistically significant level; and for instance, for the length of the shoot they are: $p < 0.001$ at $r^2 = 0.49$. At the same time, we need to remember that, according to the extant literature, the horse chestnut has one of the largest surface areas of leaves among the species of the temperate zone (Kmieć, 1997). In the situation where the space around the trees is degraded, taking measures to neutralize the negative impact of the urban environment will enable the development of the maximum size of the assimilation apparatus. As a result, this will intensify the multifaceted positive effects of woody plants on the atmosphere (CO_2 assimilation,



Ryc. 5. Zależności długości i grubości jednorocznych przyrostów pędów kasztanowca zwyczajnego *Aesculus hippocastanum* L. od: długości fazy listnienia (A–B), natężenia fotosyntezy (C–D) oraz powierzchni liści (E–F) (Źródło: opracowanie własne)
Fig. 5. Correlation between the length and thickness of annual shoots of chestnut *Aesculus hippocastanum* L. versus the length of the foliage growth phase (A–B), photosynthesis rate (C–D), and surface area of leaves (E–F) (Source: own elaboration)

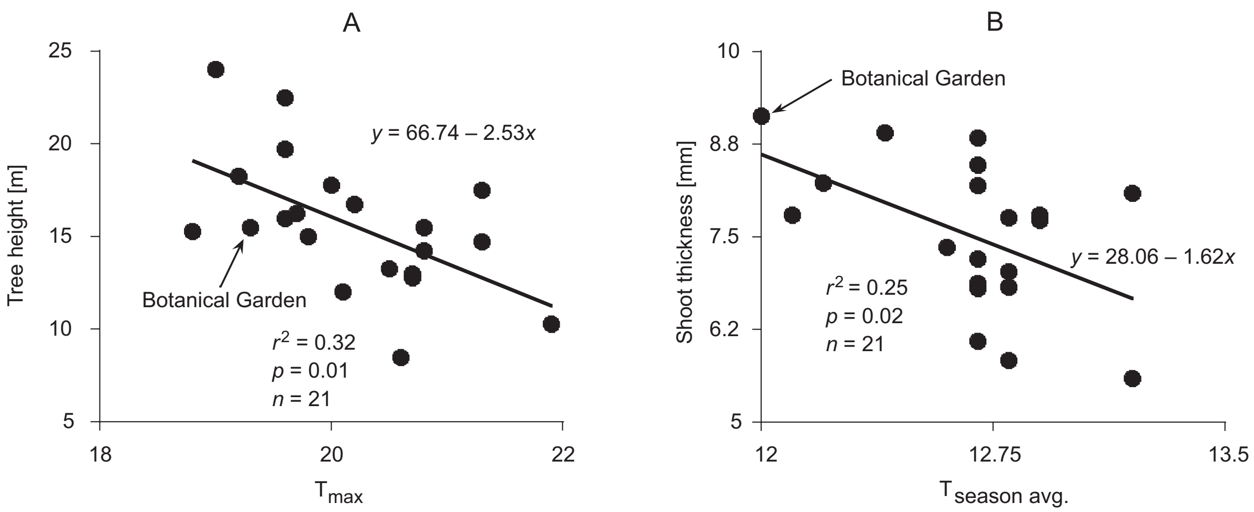
oxygen release, water transpiration, release of phytoncides, etc.). This is one of the conditions for the proper environmental management in urban and urban-industrial agglomerations.

Correlations of meteorological parameters with biometric measurements

The existence of the urban heat island directly affects the development of woody plants. Correlations of temperature measurements with biometric data indicate a clear, negative impact of elevated temperatures in urban and industrial agglomerations on the growth and thickness of annual shoots of trees (Fig. 6A–B, Tab. 1–2). This applies to maximum, average, and minimum temperatures alike (see: T_5, Tab. 1). These correlations, which are statistically significant, point to a decrease in the length and thickness of annual shoots, which results in lower tree heights. Among the consequences of higher temperatures in the city, we observe lower relative humidity, higher value of humidity deficiency, and increased drying power of the atmosphere in relation to moisture (S. Łukasiewicz and Oleksyn, 2007). Correlations of meteorological measurements with biometric increments of trees indicate a significant, unfavourable impact of abiotic factors on the development of trees. This applies to the previously discussed changes in the soil environment, changes in the parameters of the atmosphere, or the lowering of the groundwater table in cities, discussed in the subject literature (Lewińska, 2000).

SUMMARY OF FINDINGS

A characteristic feature of urban agglomerations is a degrading, damaging change in the quality of environmental components. To varying degrees, it concerns all its spheres: pedosphere, atmosphere, hydrosphere, biosphere, and anthroposphere. The decisive impact on tree increments – both positive and negative – in relation to unaltered, non-urban areas comes from those factors, which display the largest deviations compared to the reference conditions in the Botanical Garden of the Adam Mickiewicz University in Poznań (Fig. 2–5). According to the data from the subject literature and the research that the author conducted in the urban environment, these are: deficits of nitrogen, phosphorus and sulphur in the soil, oversaturation of the substrate with chloride, sodium and calcium ions, and insuffi-



Ryc. 6. Zależności wysokości drzew od temperatur maksymalnych (A) w sezonie wegetacyjnym (IV–X) oraz grubości jednorocznych przyrostów pędów od średniej temperatury sezonu wegetacyjnego (B). Dane dla 21 drzew kasztanowca zwyczajnego *Aesculus hippocastanum* L. w Poznaniu (Źródło: opracowanie własne)

Fig. 6. Correlation between tree height versus maximum temperatures (A) in the growing season (IV–X); and between the thickness of annual shoots versus the average temperature of the growing season (B). Data for 21 chestnut trees of *Aesculus hippocastanum* L. species in Poznań (Source: own elaboration)

cient size of the free, unpaved, unsealed (and thus permeable) surface around the trees. The xerism of the urban environment, both soil and air, negatively affecting the development of trees, is caused by the aforementioned sealing of the surface, preventing the possibility of rainwater infiltration, extreme values of albedo, temperature increase, decrease in humidity, and increase in the drying power of the air. This leads to a reduction in the total surface of leaves and the entire crown, a decrease in the rate of photosynthesis, and a shortening of the length of the foliage phase. As a consequence, it causes the reduction in the length and thickness of annual shoots and a reduction in the increments of trunk circumference (S. Łukasiewicz 2012 a, b; S. Łukasiewicz, Oleksyn 2007, 2012).

Knowledge of the factors limiting the development of trees in urban conditions makes it possible to take action, aimed at eliminating or reducing the negative impact of those factors on the development of trees, including their biometric parameters. The implementation of these actions will neutralize or compensate for undesirable processes in the urban environment. This, in turn, will enable trees to perform their environmental functions undisturbed – and in cities, the latter are understood in utilitarian terms, such as: CO_2 assimilation, oxygen release, water vapour transpiration, dust retention, production of phytoncides, noise suppression, etc.

CONCLUSIONS

1) Among the factors of the soil environment in the city, the most negative impact on the biometric increments of trees comes from excessive content of chlorine ions at subsequent levels of the soil profile, and to a lesser degree, of calcium ions.
2) Changes in the size of meteorological (climatic) parameters have a negative impact on the development of trees, which in turn further exacerbates the xerism of urban conditions. It is manifested by an increase in temperature, a decrease in humidity, and an increase in moisture deficiency, as well as an increase in the drying power of the air.
3) The abiotic factor significantly improving the quality of the living environment of trees in cities is the extent of the free, unpaved, unsealed and permeable soil surface around them. Sufficient soil for the proper development of trees is approximately ≥10 m^2 around the tree.
4) The parameters that significantly affect the size of biometric increments include:
   – the content of nitrogen in leaves,
   – the content of available forms of potassium and phosphorus in the soil; and also
   – length of the foliage phase,
   – surface area of leaves; and
   – the rate of photosynthesis.

Tabela 1. Statystycznie istotne korelacje między rocznymi przyrostami kasztanowca białego oraz czynnikami środowiska i cechami drzew *Aesculus hippocastanum* L. przy 21 ulicach na terenie Poznania (za: S. Łukasiewicz, 2012a, zmienione)
Table 1. Statistic's significant correlations between the annual growth of horse chestnuts and environmental factors and features of *Aesculus hippocastanum* L. trees by 21 streets in the city of Poznań (after: S. Łukasiewicz, 2012a, changed)

	Poziom Level [cm]	**CZYNNIK – FACTOR**	**Pędy 1-roczne – 1-year sprouts**		**Pień – Trunk**
			Długość Length	Grubość Thickness	Obwód Around
GLEBA/ SOIL	0–30	P	***		
		K	****		
		Mg	*		
		S		*	
		Fe	*		
		Zn	**		
		Wilgotność – Humidity		**	

	Poziom Level [cm]	**CZYNNIK – FACTOR**	**Pędy 1-roczne – 1-year sprouts**		**Pień – Trunk**
			Długość Length	Grubość Thickness	Obwód Around
		% piasku – % of sand	(–) **		
		% pyłu grub. – % of thick dust	**	**	
		% pyłu drobnego – % of slight dust	**		
	30–60	pH	(–) **	(–) **	
	30–60	K	**		
	30–60	Ca			*
	30–60	S		*	
	30–60	Na	(–) **	(–) *	
	30–60	Cl			*
	30–60	Mn			(–) ***
	30–60	% części spławialnych – % of loam			*
		Wolna, nieutwardzona powierzchnia gleby Free, non-compacted soil surface	***		
POJAWY FENOLOGICZNE PHENOLOGICAL DEVELOPMENTS		Pękanie pąków kwiatowych Cracking of flower buds	(–) **		
POJAWY FENOLOGICZNE PHENOLOGICAL DEVELOPMENTS		Intensywność owocowania Intensity of fructification	*		
POJAWY FENOLOGICZNE PHENOLOGICAL DEVELOPMENTS	Długość fazy Duration of phase:	listnienia – foliation	***	***	*
POJAWY FENOLOGICZNE PHENOLOGICAL DEVELOPMENTS	Długość fazy Duration of phase:	przebarwienia liści – discoloration of leaves	(–) *	(–) **	
POJAWY FENOLOGICZNE PHENOLOGICAL DEVELOPMENTS	Długość fazy Duration of phase:	pąków kwiatowych – flower buds	**		
POJAWY FENOLOGICZNE PHENOLOGICAL DEVELOPMENTS	Długość fazy Duration of phase:	kwitnienia – florescence		*	
POJAWY FENOLOGICZNE PHENOLOGICAL DEVELOPMENTS	Długość fazy Duration of phase:	owoców niedojrzałych – underripe fruit			****
LIŚCIE – LEAF		N	***		
LIŚCIE – LEAF		K	(–) **		
TEMPERATURA TEMPERATURE		T_{max}	(–) *		
TEMPERATURA TEMPERATURE		$T_{śr.sezon}$		(–) **	
TEMPERATURA TEMPERATURE		T_5		(–) *	
TEMPERATURA TEMPERATURE		T_{15}	(–) *		
		Natężenie ruchu [liczba pojazdów na godzinę] Intensity of traffic (number of vehicles per hour)	(–) **		

Poziom istotności / Level of significance: **** < 0.001; *** ≤ 0.01; ** ≤ 0.05; * < 0.1
(–) – korelacja ujemna / negative correlation
T_{max} – temperatura maksymalna w ciągu sezonu wegetacyjnego/ maximum temperature during vegetative season
$T_{śr.sezon}$ – średnia temperatura w ciągu sezonu wegetacyjnego/ mean temperature during vegetative season
T_5 – średnia temperatura o godz. 5.00/ mean temperature at 5 am
T_{15} – średnia temperatura o godz. 15.00/ mean temperature at 3 pm

Tabela 2. Zestawienie wybranych parametrów osobników *Aesculus hippocastanum* L., wolnej powierzchni gleby wokół drzew, natężenia ruchu pojazdów oraz temperatury maksymalnej odnotowanych przy 21 ulicach na terenie Poznania. Puste miejsca oznaczają brak danych. Na ośmiu stanowiskach wyróżnionych ciemniejszym tłem wykonywano szczegółowe analizy chemizmu liści i wymiany gazowej (Źródło: opracowanie własne)
Table 2. Summary of selected parameters of *Aesculus hippocastanum* L., free, unsealed soil area around the trees, traffic intensity and maximum temperature recorded at 21 streets in Poznań. Blank spaces mean that there is no available data. Darker background indicates that a detailed analysis of leaf chemistry and gas exchange was conducted in the 8 locations (Source: own elaboration)

Ulica * Street*	Podział stanowisk wg jakości siedliska** Sequence of trees by habitat quality**	Nr drzewa Tree number	Lata obserwacji fenologicznych Years of phenological observations	Wysokość [m], 2000r. High [m] in 2000	Promień korony [m] 2000r. Tree crown radius [m] in 2000	Obwód pnia [m], 2000r. Trunk circumference [m] in 2000	Przyrost pędu [cm], 1997 Shoot increment [cm] in 1997	Grubość pędu [mm], 1997 Shoot thickness [mm] in 1997	Masa nasiona [g], 1998 Mass of seeds [g] in 1998	Wolna powierzchnia gleby m^2 2000 r. Unsealed soil surface m^2 in 2000	Natężenie ruchu [pojazdy/h] Traffic [no. of vehicles per hour] in 1995–1998	Temp. max. [°C] lipiec, 1999 Maximum temperature [°C] in July 1999
Matejki	A	1	1994–1999	22.50	6.0	2.10	19.7	7.2	27.4	420	862	32.8
Matejki	A	2	1997–1999	18.75	4.5	1.70	4.8	6.3	15.5	50	862	
Wieniawskiego	A	1	1994–1995	13.25	5.5	1.70	6.3	8.5	14.5	1	50	34.4
Jerzego	B	1	1995–1999	15.25	6.0	1.80	8.8	8.9	20.5	110	850	31.9
Jerzego	B	2	1997–1999	15.50	5.0	1.00	8.3	7.0	16.0	90	850	
Ogród Botaniczny	B	1	1995–1999	15.50	6.0	1.70	8.3	9.1	15.4	450	0	32.8
Ogród Botaniczny	B	2	1997–1999	15.00	5.0	1.85	15.2	8.1	11.1	315	0	
Prusa	B	1	1995–1999	16.25	5.0	1.95	8.7	7.8	15.3	30	350	33.6
Grunwaldzka-II	C	1	1994–1999	14.75	5.0	1.75	5.3	8.1		1	1708	34.9
Grunwaldzka-II	C	2	1997–1999	15.75	7.5	1.79	10.0	6.7	15.6	1	1708	
Staszica	C	1	1994-1999	17.75	4.5	1.90	7.5	8.2	15.0	55	1837	33.2
Głogowska-I	D	1	1994–1999	16.75	5.0	1.60	3.2	6.1	23.7	60	1247	33.2
Kościelna	D	1	1994–1999	19.75	7.0	2.45	4.0	7.7	18.4	5	1456	33.6
Kosińskiego	D	1	1995–1999	15.00	7.0	2.37	6.3	6.8	18.6	1	850	32.8
Noskowskiego	D	1	1994–1999	15.50	6.0	1.60	10.5	7.8	14.2	450	50	34.0
Noskowskiego	D	2	1997–1999	16.75	5.5	2.00	7.5	8.4	14.5	95	50	
Spadzista	D	1	1994–1999	24.00	8.0	2.60	9.2	8.2	20.5	750	1282	31.1

Ulica * Street*	Podział stanowisk wg jakości siedliska** Sequence of trees by habitat quality**	Nr drzewa Tree number	Lata obserwacji fenologicznych Years of phenological observations	Wysokość [m], 2000r. High [m] in 2000	Promień korony [m] 2000r. Tree crown radius [m] in 2000	Obwód pnia [m], 2000r. Trunk circumference [m] in 2000	Przyrost pędu [cm], 1997 Shoot increment [cm] in 1997	Grubość pędu [mm], 1997 Shoot thickness [mm] in 1997	Masa nasiona [g], 1998 Mass of seeds [g] in 1998	Wolna powierzchnia gleby m^2 2000 r. Unsealed soil surface m^2 in 2000	Natężenie ruchu [pojazdy/h] Traffic [no. of vehicles per hour] in 1995–1998	Temp. max. [°C] lipiec, 1999 Maximum temperature [°C] in July 1999
Spadzista	D	2	1997–1999	18.75	7.0	1.86	13.3	8.9	21.8	570	1282	
Staszica	D	2	1997–1999	14.50	3.0	1.17	1.5	6.2		65	1837	
Święcickiego	D	1	1994–1999	12.00	4.5	1.60	5.3	7.4	18.4	20	1708	33.2
Święcickiego	D	2	1995–1999	14.75	5.7	1.55	2.7	6.4	13.6	1	1708	
Ułanska	D	1	1994–1999	17.50	7.0	2.00	4.5	6.8	13.0	310	1923	35.3
Ułanska	D	2	1995–1999	21.00	9.0	2.50	8.3	8.3	13.4	1020	1923	
Wojskowa	D	1	1994–1999	12.75	6.1	1.95	4.3	6.9	13.4	140	936	34.9
Wojskowa	D	3	1995–1999	12.25	5.5	1.60	5.3	6.9	13.9	45	936	
Aleja Wielkopolska	E	1	1996–1999	16.00	6.5	1.92	4.7	7.8	10.9	530	830	32.3
Aleja Wielkopolska	E	2	1996–1999	11.25	4.5	1.42	3.2	6.0		125	830	
Bema	E	1	1994–1999	8.50	3.5	0.95	9.8	8.8	21.5	10	1756	34.0
Bema	E	2	1995–1999	8.25	4.0	1.00	8.8	8.8		50	1756	
Dominikańska	E	1	1995–1999	14.25	5.0	1.80	8.0	5.6	17.8	0.5	2323	34.4
Dominikańska	E	2	1997–1999	14.00	4.0	1.70	2.5	5.7		0.5	2323	
Kościuszki	E	1	1994–1999	18.25	6.5	1.95	5.5	6.8	14.3	1	427	32.8
Głogowska-II	F	1	1994–1999	13.00	6.3	1.95	3.5	5.8		135	2362	34.0
Grunwaldzka-I	F	1	1994–1999	10.25	4.0	1.45	2.2	7.0		2	1708	36.6
Grunwaldzka-I	F	6	1995–1999	10.00	4.5	1.45	2.7	7.1	11.0	2	1708	

● – rozmieszczenie stanowisk przedstawia rycina 1 * – locations of research sites are shown in Fig. 1
** – Drzewa na stanowiskach wymieniono od siedlisk najlepszych (A) do najgorszych (F), zgodnie ze wzrostem negatywnego oddziaływania danego stanowiska na drzewa, na podstawie pięcioletnich badań rytmiki sezonowej kasztanowca zwyczajnego *Aesculus hippocastanum* L. (za: S. Łukasiewicz, 2002)
** – Trees along the streets are listed according to habitat quality from the best (A) to the worst (F), indicating the increase in the negative impact of a given site on trees, based on a five-year study of the seasonal rhythmicity of the horse chestnut *Aesculus hippocastanum L.* (after: S. Łukasiewicz, 2002)

REFERENCES

Bartkowski, T. 1991. Kształtowanie i ochrona środowiska człowieka. Warszawa: Państwowe Wydawnictwo Naukowe.

Blume, H.P. (1989). Classification of soils in urban agglomerations. Catena, 16, 269–275.

Bornstein, R.D. (1968). Observations of the urban hit islands effect in New York City. J. Appl. Meteorol. 7, 575–582.

Bredshaw, A., Hunt, B., Walmsley, T. (1996). Threes in the urban landscape. Principles and Practice. London: Chapman & Hall.

Breś, W., Golcz, A., Komosa, A., Kozik, E., Tyksiński, W. (2003). Nawożenie roślin ogrodniczych. Poznań: Wydawnictwo AR.

Bullock, P., Gregory, P.J. (ed.) (1991). Soils in the urban environment. Oxford: Blackwell.

Douglas, I. (1983). The urban environment. Baltimore, MD: Edward Arnold.

Fober, H. (1990). Mineralne żywienie. [In:] S. Białobok (ed.), Buk zwyczajny. Warszawa–Poznań: PWN, 143–157.

Fober, H. (1993). Żywienie mineralne. [In:] W. Bugała (ed.), Grab zwyczajny. Warszawa–Poznań: PWN, 87–95.

Fober, H. (1995). Mineralne żywienie. [In:] W. Bugała (ed.), Jesion wyniosły. Warszawa–Poznań: PWN, 137–147.

Fober, H. (1999). Mineralne żywienie. [In:] W. Bugała (ed.), Klony. Warszawa–Poznań: PWN, 147–162.

Gliński, J. (1999). Chemiczne i fizykochemiczne właściwości gleb. [In:] S. Zawadzki (ed.), Gleboznawstwo. Warszawa: PWRiL, 183–236.

Gorlach, E., Mazur, T. (2002). Chemia rolna. Warszawa: Wydawnictwo Naukowe PWN.

Guha, M.M., Mitchell, R.L. (1966). The trace and major element composition of the leaves of some deciduous trees. II. Seasonal changes. Plant and Soil, 24, 90–112.

Hodge, S.J. (1995). Creating and managing woodlands around towns. Forestry Commission Handbook 11. London: HMSO.

IUNG (1983). Metody badań laboratoryjnych w stacjach chemiczno-rolniczych. Cz. IV. Badanie gleb, ziem i podłoży oraz części wskaźnikowych roślin w celach diagnostycznych.

Kabata-Pendias, A., Pendias, H. (1999). Biogeografia pierwiastków śladowych. Warszawa: PWN.

Kmieć, K. (1997). Ocena zawartości escyny w nasionach kasztanowca *Aesculus hippocastanum* L. Rozprawa doktorska. Katedra Farmakognozji. Collegium Medicum UJ, Kraków.

Landsberg, H.E. (1981). The urban climate. International Geophysics Series, 28. London: Academic Press.

Lewińska, J. (2000). Klimat miasta. Zasoby, zagrożenia, kształtowanie. Kraków: Instytut Gospodarki Przestrzennej i Komunalnej.

Łukasiewicz, A. (1984). Potrzeba ujednolicenia metodyki fenologicznej w polskich Ogrodach botanicznych i arboretach. Biuletyn Ogrodów Botanicznych, Muzeów i Zbiorów. Wiadomości Botaniczne, 28(2), 153–158.

Łukasiewicz, S. (2002). Wpływ wybranych czynników na rozwój kasztanowca białego *Aesculus hippocastanum* L. w warunkach miejskich Poznania. Praca doktorska, Wydział Biologii UAM, Poznań, mscr.

Łukasiewicz, S. (2012a). Struktura fizyczna gruntu, skład chemiczny gleb oraz zawartość substancji organicznej w podłożach 21 stanowisk zieleni miejskiej ekosystemu Poznania, cz. III. Zawartość makroelementów. Badania Fizjograficzne, R. III, Seria A – Geografia Fizyczna, 7–47.

Łukasiewicz, S. (2012b). Struktura fizyczna gruntu, skład chemiczny gleb oraz zawartość substancji organicznej w podłożach 21 stanowisk zieleni miejskiej ekosystemu Poznania, cz. IV. Zawartość mikroelementów. Badania Fizjograficzne, R. III, Seria A – Geografia Fizyczna, 49–75.

Łukasiewicz, S., Oleksyn J. (2007). Zróżnicowanie przestrzenne elementów meteorologicznych i ich wpływ na rozwój kasztanowca zwyczajnego (*Aesculus hippocastanum* L.) w warunkach miejskich Poznania. Badania Fizjograficzne Nad Polską Zachodnią, Seria A – Geografia Fizyczna,, 58, 47–78.

Łukasiewicz, S., Oleksyn J. 2012. Rekompensujący wpływ wolnej, nieutwardzonej powierzchni gleby wokół drzew, na ich rozwój w warunkach środowiska miejskiego, na przykładzie kasztanowca białego *Aesculus hippocastanum* L. Badania Fizjograficzne, R. III, Seria B – Botanika, 155–165.

Marschner, H. (1995). Mineral Nutrition of Higher Plants, 2nd edition. London, San Diego: Academic Press.

McDonnell, M.J., Pickett, S.T.A. (1990). The study of structure and function along urban-rural gradiens: An unexploited opportunity for ecology. Ecology, 71, 1231–1237.

Miller, R.W. (1996). Urban forestry. Planning and managing urban greenspaces, 2nd edition. Upper Saddle River, New Jersey: Prentice Hall.

Mocek, A. (ed.) (2015). Gleboznawstwo. Warszawa: Wydawnictwo Naukowe PWN.

Moll, G., Ebenreck, S. (ed.) (1989). Shading our cities. A resource guide for urban and community forests. Washington, D.C., Covelo: Island Press.

Molski, B. (1976). Wyniki badań fenologicznych. [In:] H. Kryczyńska (ed.), Rozwój roślin w środowisku miejskim na przykładzie Warszawy. Warszawa: Ogród Botaniczny PAN, 43–55.

Mooney, H.A. (1986). Physiological ecology of coastal subalpine and alpine populations of Polygonum bistortioides. Ecology, 44, 812–816.

Nowosielski, O. (1974). Metody oznaczania potrzeb nawożenia. Warszawa: PWRiL.

Nowosielski, O. (1988). Zasady opracowywania zaleceń nawozowych w ogrodnictwie. Warszawa: PWRiL.

Oleksyn, J., Żytkowiak, R., Reich, P.B., Tjoelker, M.G., Karolewski, P. (2000). Ontogenetic pattern of leaf CO_2 exchange, morphology and chemistry in Betula pendula trees. Trees, 14, 271–281.

Oleksyn, J., Kloeppel, B.D., LukasiewiczS., Karolewski, P., Reich, P.B. (2007). Ecophysiology of horse chestnut (*Aesculus hippocastanum* L.) in degraded and restored urban sites. Polish Journal of Ecology, 55(2), 245–260.

Schleuss, U., Wu, Q., Blume, H.P. (1998). Variability of soils in urban and periurban areas in Northern Germany. Catena, 33, 255–270.

Starck, Z. (2002). Gospodarka mineralna roślin. [In:] J. Kopcewicz, S. Lewak (eds.), Fizjologia roślin. Warszawa: Wydawnictwo Naukowe PWN, 228–271.

Wittig, R. (1991). Okologie der Grossstadtflora. Stuttgart: UTB Ulmer-Verlag.

Zimny, H. (1973). Miejskie warunki ekologiczne a roślinność drzewiasta. Materiały z Sympozjum pt. Problemy pielęgnacji i ochrony drzew w aglomeracjach miejskich i obiektach zabytkowych. Łańcut.

WPŁYW CZYNNIKÓW ŚRODOWISKA MIEJSKIEGO NA WZROST KASZTANOWCA ZWYCZAJNEGO *AESCULUS HIPPOCASTANUM* L.

ABSTRAKT

Cel pracy

W latach 1995–1999 w 21 punktach szeroko rozumianego centrum Poznania prowadzono badania dotyczące rozwoju kasztanowca zwyczajnego *Aesculus hippocastanum* L. W ramach tych badań przeanalizowano znaczenie wybranych czynników środowiskowych. Celem badań było poznanie warunków rozwoju drzew w przestrzeni miejskiej i przemysłowej aglomeracji poznańskiej.

Materiały i metody

Znajomość czynników ograniczających wzrost drzew w warunkach miejskich pozwala na podjęcie zabiegów, które będą te czynniki eliminować lub ograniczać ich negatywny wpływ na rozwój drzew, w tym na ich parametry biometryczne. Realizacja takich zabiegów zneutralizuje lub zrekompensuje niepożądane procesy zachodzące w środowisku miejskim. W rezultacie pozwoli to na nieograniczoną realizację istotnych funkcji ekosystemowych drzew, takich jak: asymilacja CO_2, uwalnianie tlenu, transpiracja pary wodnej, retencja pyłu, produkcja fitoncydów czy tłumienie hałasu.

Wyniki i wnioski

Badania rozwoju 35 drzew kasztanowca zwyczajnego na 21 ulicach obejmowały: rytmikę sezonową drzew, zapis temperatury i wilgotności powietrza, analizy fizyczno-chemiczne podłoża, pomiary biometryczne, a także, na ośmiu stanowiskach, wybrane parametry fizjologiczne, takie jak natężenie fotosyntezy i transpiracji. Łącznie zebrano ponad 17 000 danych liczbowych na temat środowiska. Ryciny zamieszczone w niniejszym artykule przedstawiają głównie zależności między czynnikami środowiskowymi i parametrami biometrycznymi jako istotne statystycznie, np. dla $p \leq 0{,}01$.

Słowa kluczowe: *Aesculus hippocastanum* L., ekologia miasta, pomiary biometryczne