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KLOROFILL VIZSGÁLATOK A BUDAI ARBORÉTUM FÁSSZÁRÚ GYŰJTEMÉNYÉBEN

CHLOROPHYLL STUDIES IN THE WOODY PLANT COLLECTION OF THE BUDA ARBORETUM

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ABSZTRAKT

A klímaváltozás és az urbanizáció intenzitásának növekedése jelentős hatást gyakorol a városi ökoszisztémákra, ezért a zöld infrastruktúra fenntarthatósága különös figyelmet igényel. E rendszerek alapvető elemei közé tartoznak a fásszárú növények, amelyek nemcsak árnyékot biztosítanak és hozzájárulnak a biodiverzitáshoz, hanem kiemelt ökoszisztéma-szolgáltatásokkal – például a hőmérséklet szabályozásával és a légszennyezés csökkentésével – is nélkülözhetetlen szerepet töltenek be. A különböző taxonok azonban eltérő mértékben járulnak hozzá az ökoszisztéma-szolgáltatásokhoz. Emiatt folyamatosan keressük azokat a fajokat, fajtákat, amelyek a városi környezethez leginkább alkalmazkodnak, és hozzájárulnak a klímaváltozás és az urbanizáció kedvezőtlen hatásainak mérsékléséhez. Az egyes taxonok adaptációs képességének és fiziológiai állapotának értékelésére számos indikátor áll rendelkezésre. Ahhoz, hogy megértsük a városi környezetben alkalmazott fásszárú taxonok ökoszisztéma-szolgáltatási potenciálját, kutatásunk első szakaszában a levelek klorofill-tartalmára fókuszáltunk, hiszen a klorofill mennyisége szoros összefüggésben áll a fotoszintetikus aktivitással és az oxigéntermeléssel. A mérések célja, hogy összehasonlítsuk a már alkalmazásban lévő fajok, fajták és más potenciálisan alkalmazható taxonok klorofill-tartalmát és a vegetációs időszak alatti változását. A méréseket a Budai Arborétumban végezzük, ahol közel 100 fásszárú egyedet (fákat és cserjéket) választottunk ki. Előzetes méréseink szerint az örökzöld fajok juvenilis (morfológiailag és anatómiailag nem teljesen fejlett) és idős leveleinek (teljesen kifejlődött, funkcionálisan aktív vagy már öregedő levél) klorofill tartalmában még nyáron is szignifikáns eltérések figyelhetők meg. Jelentős különbségek mutatkoztak továbbá a nemzetségek összehasonlítása során, esetenként olyan taxonoknál is, amelyek a városi növényalkalmazásban hasonló szerepben jelennek meg.

Kulcsszavak: klorofill-tartalom; városfásítás; növényalkalmazás; ökoszisztéma-szolgáltatás ⦿

ABSTRACT

Climate change and the increase in urbanisation intensity have a significant impact on the ecosystems of forests, so the sustainability of green infrastructure requires particular attention. Among the essential elements of these systems are woody plants, which not only provide shade and contribute to biodiversity, but also play an indispensable role by providing key ecosystem services such as temperature regulation and air pollution reduction. However, different taxa contribute to ecosystem services to different degrees. For this reason, we are constantly looking for species that are best adapted to urban environments and contribute to mitigating the negative effects of climate change and urbanisation. Several indices are available to assess the adaptive capacity and physiological status of individual taxa. In order to understand the ecosystem service potential of woody taxa in urban environments, the first phase of our research focused on the chlorophyll content of leaves, as chlorophyll content is closely related to photosynthetic activity and oxygen production. The aim of the measurements is to compare the chlorophyll content of species, cultivars and other potentially applicable taxa already in use and their variation during the growing season. The measurements will be carried out in the Buda Arboretum, where about 100 woody species (trees and shrubs) have been selected. Our preliminary measurements show significant differences in the chlorophyll content of juvenile (morphologically and anatomically underdeveloped) and old leaves (fully developed, functionally active or already senescent) of evergreen species even in summer. Significant differences were also found when comparing genera, sometimes with taxa that play a similar role in urban plant use.

Keywords: chlorophyll content; urban afforestation; plant application; ecosystem services

INTRODUCTION

In today's urbanised environment, abiotic (such as temperature, air pollution) and biotic (such as the spread of invasive species and pathogens and pests) factors that affect the ecosystem are influencing urban life to such an extent that their effects are directly felt in our daily lives (Pongrácz, 2011).

In this constantly and radically changing environment, the role of urban green infrastructure, often consisting of

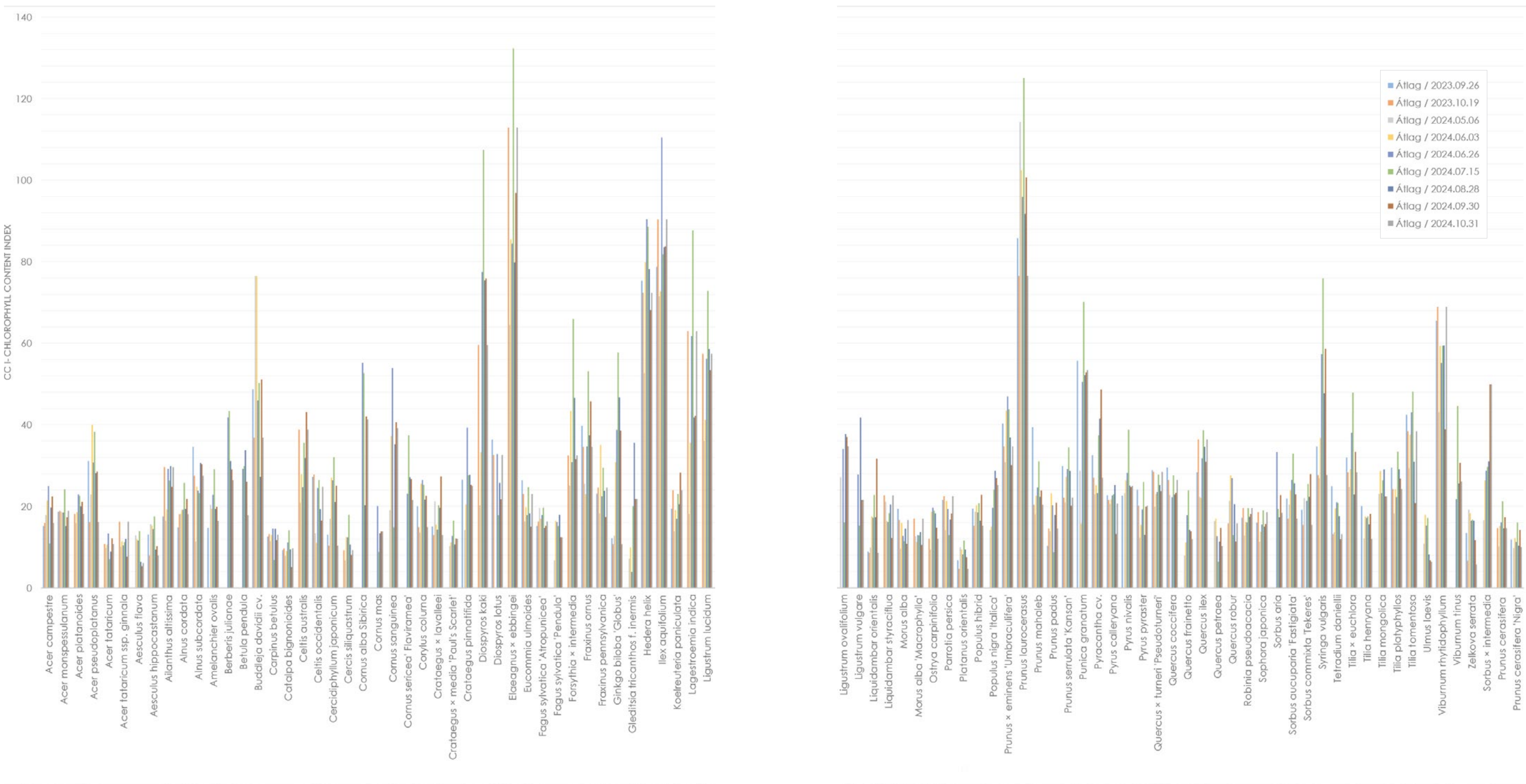
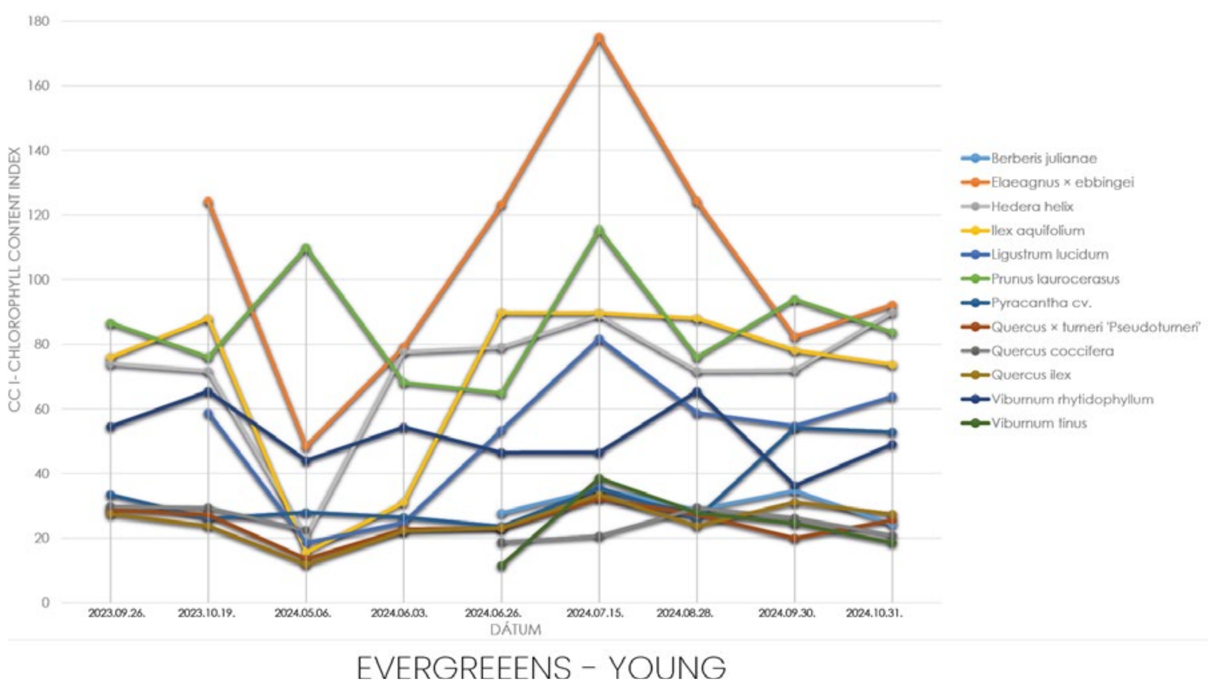
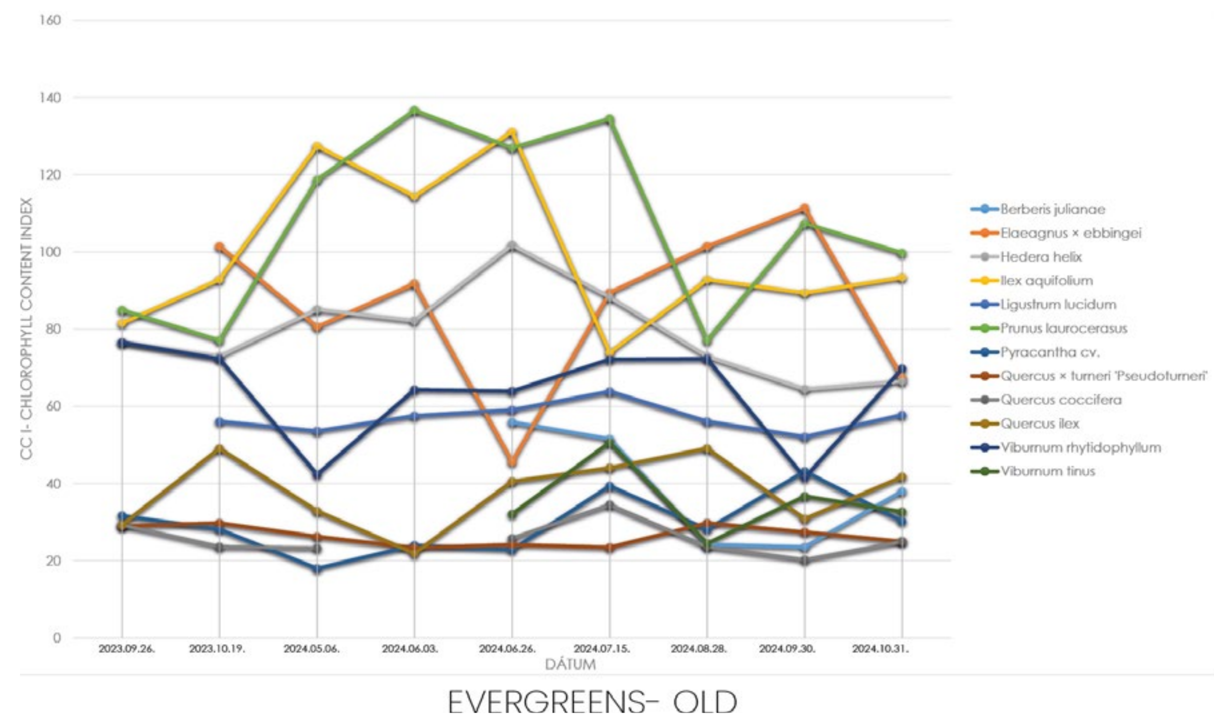


Figure 1: Taxa assessed according to the 2022 Recommended List of Species

Figure 2: Comparison of young (left side) and old (right side) leaves of evergreen taxa in terms of chlorophyll content





interconnected elements such as treelines, green strips and groves, is essential. Urban green spaces also play a key role as interconnected green corridors from an ecological, environmental, townscape and microclimatic point of view (Gill et al, 2007; Gyimóthy, 2015; Nowak, 2001; Parmesan, 2006; Tutundzic, 2019).

Woody taxa are fundamental components of ecosystems and are of particular importance for ecosystem services, as larger and longer-lived species provide the most significant contribution to ecosystem services (Parmesan, 2006; Venter et al., 2024), including carbon sequestration, oxygen production, water regulation, soil protection, and biodiversity maintenance, as well as recreational and aesthetic values (Livesley et al., 2016). The environmental tolerance of the species and varieties used, as well as their resistance to pests and pathogens, are essential considerations in urban afforestation (Böll, 2018; Nádasy & Valánszki, 2021; Roloff et al., 2009; Rosa & Szabó, 2021; Susanne et al., 2018; Tóth et al., 2024). Previous research shows that leaf chlorophyll content, as an indicator of photosynthetic activity, is directly proportional to oxygen production and to the improvement of climatic conditions (Cavender-Bares et al., 2022; Nowak, 2001; Nowak et al., 2008; Scheifinger et al., 2002).

In order to mitigate the effects of climate change and urbanisation, we are constantly looking for species that are best adapted to urban environments. We aim to select taxa with outstanding ecosystem services. Our long-term research aims to investigate the ecosystem services of woody taxa already used in urban environments, as well as those that have potential but are currently rarely used. This complex, interdisciplinary research will require collaboration between different disciplines, and modern measurement and modelling techniques will, according to Hirabayashi (2022), allow for a more accurate assessment of ecosystem services(Bolund & Hunhammar, 1999; Hirabayashi et al., n. d.; Kiss, 2019; Suchocka et al., 2023). The results can contribute to a more effective protection and sustainable use of natural resources and to reducing the negative impacts of climate change. The comparison of data collected during field measurements during the growing season with meteorological data will help us understand the relationship between chlorophyll production and chlorophyll content of species and varieties and abiotic factors. Urban tree diversity is key to sustainability, and the integration of new species from other USDA zones (8a, 8b) may be a focus for future work.

Our preliminary research focuses on a single plant-life element of the ecosystem services provided by woody plants, the amount of chlorophyll in individual leaves forming the canopy, and its variation over time. The measured chlorophyll values are species-specific and vary over time (von Caemmerer & Farquhar, 1981; Bodor-Pesti et al., 2025), so by following them over the growing season we can get a comprehensive picture of the relationship between phenological phases and chlorophyll content. Furthermore, our research will also reveal differences between juvenile and old leaves of evergreen

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species. Our research seeks to answer several questions: ① What are the differences in chlorophyll concentration values between the taxa studied; ② What are the differences between genera? ③ What distribution of chlorophyll content can be found between the different life forms, i.e. trees and shrubs? ④ What differences, if any, do young and old leaves show between evergreens and deciduous trees?

SUBSTANCE AND METHOD

For the studies, 91 taxa from the collection of the Buda Arboretum were evaluated. For the selection we took into account the taxa listed in the Inventory of Public Shrubs (2022) (Szabó, 2022), as well as other potentially applicable tree and shrub species in the literature (Blanusa et al., 2019; Cavender-Bares et al., 2022; Gómez-Muñoz et al., 2010; Konijnendijk, 2008; Roloff et al., 2009; Sjöman et al., 2012). Chlorophyll content measurements were carried out nine times, starting in September 2023. Of the total number of species selected, 50 different taxa recommended by the 2022 updated Inventory of Public Shrubs and Trees, and 41 shrub and tree habitats were tested (Figure 1).

The study site is the Buda Arboretum, located in the south-eastern part of the Buda Hills, on the boundary between the upland and lowland climate zones. Annual precipitation here ranges from 600–620 mm. The soils of the study area are mostly moderately to heavily calcareous, poor in humus and alkaline (pH 8.0). During the measurement period (autumn 2023 to autumn 2024), the autumn and winter of 2023/2024 and the spring of 2024 were the warmest, based on climate data available from 1901. The growing season started earlier than usual, in February and March. The seasonal average temperature in Budapest (15 °C) was 3.9 °C above the multi-year average for 1991–2020 (11.1 °C). Precipitation varied between 120 and 140 mm, with a very uneven distribution (Szolnoki-Tótiván, 2024).

Chlorophyll is measured using the Apogee Instruments® MC-100 instrument (S/N:1999, USA), which is suitable for rapid and accurate determination of chlorophyll content under field conditions. The instrument performs a non-destructive, optically based measurement, calculating the chlorophyll content of leaves from the spectral composition of reflected light. The device emits light at two wavelengths, 635 nm (red) and 700 nm (infrared), and measures the reflectance. Based on the reflected light, the instrument measures the relative chlorophyll content, which is given by CIRAD as the Chlorophyll Content Index (CCI). This is a dimensionless index, calculated from the measured red and infrared reflectance, and therefore does not indicate a specific quantitative chlorophyll content (μg/cm²) but a relative value used to compare samples. The advantage of the MC-100 tool is that, although it does not give direct concentration values, the CCI index allows accurate comparison of changes in chlorophyll levels by taxon and growing season, which is ideal for field comparisons and long-term

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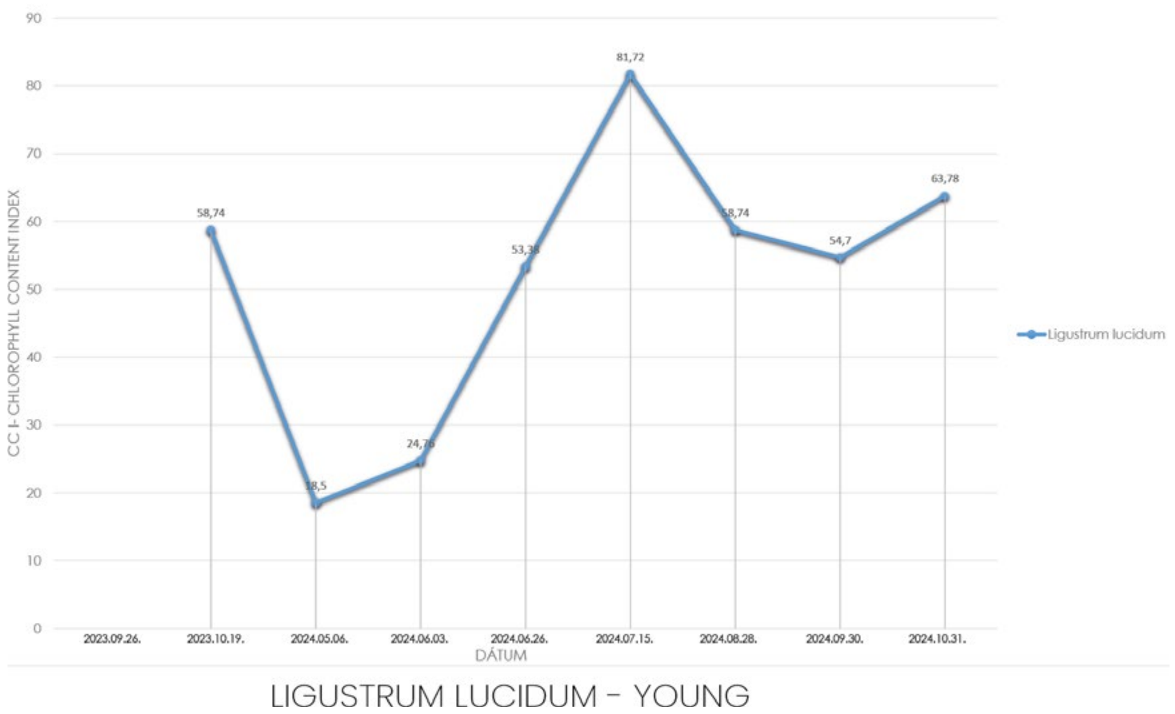

trend analysis (Bodor-Pesti et al., 2023; Immanuel & Miruna, 2024; *MC-100-spec-sheet.pdf*, n. d.; Parry et al., 2014).

The measurements were made on samples taken from the ground level, from the outer part of the crown (light leaves), ten samples per individual for deciduous plants and five samples per taxon for evergreens, separating young and older leaved plants. To evaluate the results of the preliminary studies, charts were prepared (Excel Version 2407).

RESULTS

The trend observed in the nine measurements was for chlorophyll values to steadily increase until June, reaching maximum values in July. Thereafter, a decrease in CCI values was observed for most deciduous taxa. For evergreen taxa, it was also observed that they reached absolute peak values in July, but after a decrease in August, a slight increase was observed in the September and October monthly measurements. The chlorophyll content of evergreens and deciduous taxa (which shed their leaves in a prolonged, delayed manner or even retain them during mild winters) varied widely, with a minimum value of 11.5 and a maximum of 175.1 CCI. This last value was measured on the leaves of *Diospyros kaki* in July.

Among the trees listed in the Public Inventory of Shrubs and Trees from 2022, the representatives of the genera *Prunus* and *Tilia* and the species *Ginkgo biloba* 'Globus' stood out, with an average chlorophyll value of 35 CCI in June 2024, while the highest values in July were obtained by *Fraxinus ornus* (53.1), *Ginkgo biloba* 'Globus' (57.7), *Prunus × eminens* 'Umbraculifera' (43.8), *Tilia × euchlora* (47.9) and *Tilia tomentosa* (48.1).

Among the unlisted taxa, *Diospyros kaki* (107.5), *Lagerstroemia hybrid* (87.7), *Ligustrum lucidum* (72.8) and *Punica granatum* (70.1) were the tree habitat species with the highest absolute values. For shrubs, the absolute highest values were recorded on the leaves of *Elaeagnus × ebbingei* (132.3), but also on *Buddleja davidii* (76.5), *Hedera helix* (90, 4), *Ilex aquifolium* (110.4), *Prunus laurocerasus* (125.0), *Syringa vulgaris* (75.9) and *Viburnum rhytidophyllum* (68.9), which also showed outstanding values.

The chlorophyll values of young leaves of evergreen and deciduous species ranged widely, with a minimum of 11.5 and a maximum of 175.1. The values increased steadily until the July measurement, but then showed very different variations in the August–October period. The measurements of *Ilex aquifolium* leaves from July to October show a slow decrease in the values of young leaves (89.7; 89.7; 87.9; 78.1; 73.7). The values of *Viburnum rhytidophyllum* showed a stagnation in the middle of the growing season (46.4 in June and 46.5 in July), but in August the values increased to 65.4, and then only 36.2 in September. A slight increase was then observed at the end of October, when the chlorophyll content rose to 49.0. The values of *Ligustrum ovalifolium* decreased in June and July (30.6; 15.9), but a slight

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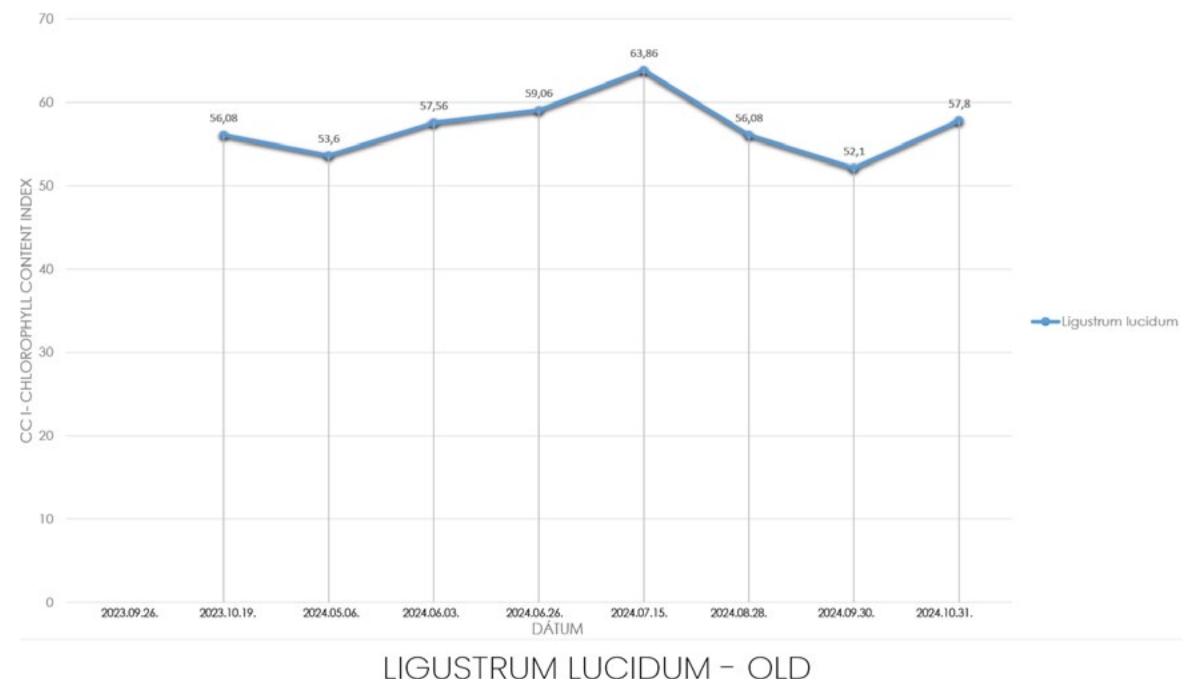
Figure 3: Comparison of chlorophyll levels in young (left side) and old (right side) leaves of Ligustrum lucidum



increase was observed in the next three measurements (31.7; 37.4; 35.4).

The values of the old leaves ranged more narrowly than those of the juvenile leaves, with a minimum of 17.9 and a maximum of 136.7. In the evergreen *Quercus* genus, there was no significant difference between young and old leaves. Smaller fluctuations were observed for *Hedera helix,* where values increased steadily until June to 101.8, followed by a decrease in the next 4 measurements (88.2; 72.9; 64.4; 66.4). The values for *Viburnum rhytidophyllum* showed a slight stagnation in June–August, with a minimum value of 63.9 and a maximum of 72.3. Subsequently, the value for old leaves approached again the values measured previously (69.8). No significant differences in leaf age were detected for the taxa *Hedera helix,* or *Quercus × turneri* 'Pseudoturneri'. However, the chlorophyll content of juvenile leaves of *Elaeagnus × ebbingei* was already higher than that of the old leaves (91.8; 45.6; 89.5) in June and July (79.1; 123.2; 175.1). In the next two measurements, the values of the old leaves continued to increase up to 111.3, and then decreased drastically to 67.4 in October. In contrast, the maximum value for young leaves was recorded in July (175.0), after which the measured values steadily decreased (124.2; 82.3; 92.1). The decrease in the value of young leaves was also observed for *Ligustrum lucidum* after the peak in July (81.7) (58.7; 54.7; 63.7), while the values for old leaves were much narrower (minimum 52.1, maximum 63.8) (Figure 3). It can also be observed that the chlorophyll content of young leaves exceeded the values of old leaves by June and then, after a slight decrease, reached the values of old leaves.

In comparing the values of young and older leaves, it was found that the values measured on the young leaves of most of the species examined reached the values measured on the older leaves by the 25th–30th week (Figure 2).

During the measurements, we observed that there can also be large variations within genera. For maples, the highest values were obtained for *Acer pseudoplatanus* among the 6 species tested, while the lowest values were observed for *Acer tataricum* (7.0–13.2) and *A. t.* subsp. *ginnala* (7.6–16.2). Among the deciduous *Prunus, Prunus × eminens* 'Umbraculifera' showed the highest values (30.1–46.9), but *P. mahaleb* (18.0–39.4) and *P. serrulata* 'Kanzan' (20.1–34.4) also gave above average values. Among the linden species (Fig. 5), *T. tomentosa* (20.8–48.0) and *T. × euchlora* (22.8–47.9) had the highest chlorophyll content in the measurements. The highest values of *T. henryana* (12.1–20.0) did not reach the range above 20 CCI. For evergreen oaks, the highest values were measured on leaves of *Q. ilex* (22.0–38.6), while the other two evergreens *Q. × turneri* 'Pseudoturneri' (19.8–28.8) and *Q. coccifera* (22.2–29.5) were nearly identical. It is noteworthy, however, that the June values of the deciduous *Q. robur* (27.5 and 26.9) exceeded those of the two evergreen taxa measured at the same time. In oaks, the lowest results were observed on *Q. petraea* (6.4–17.0), which could be due to the heavy powdery mildew infestation.

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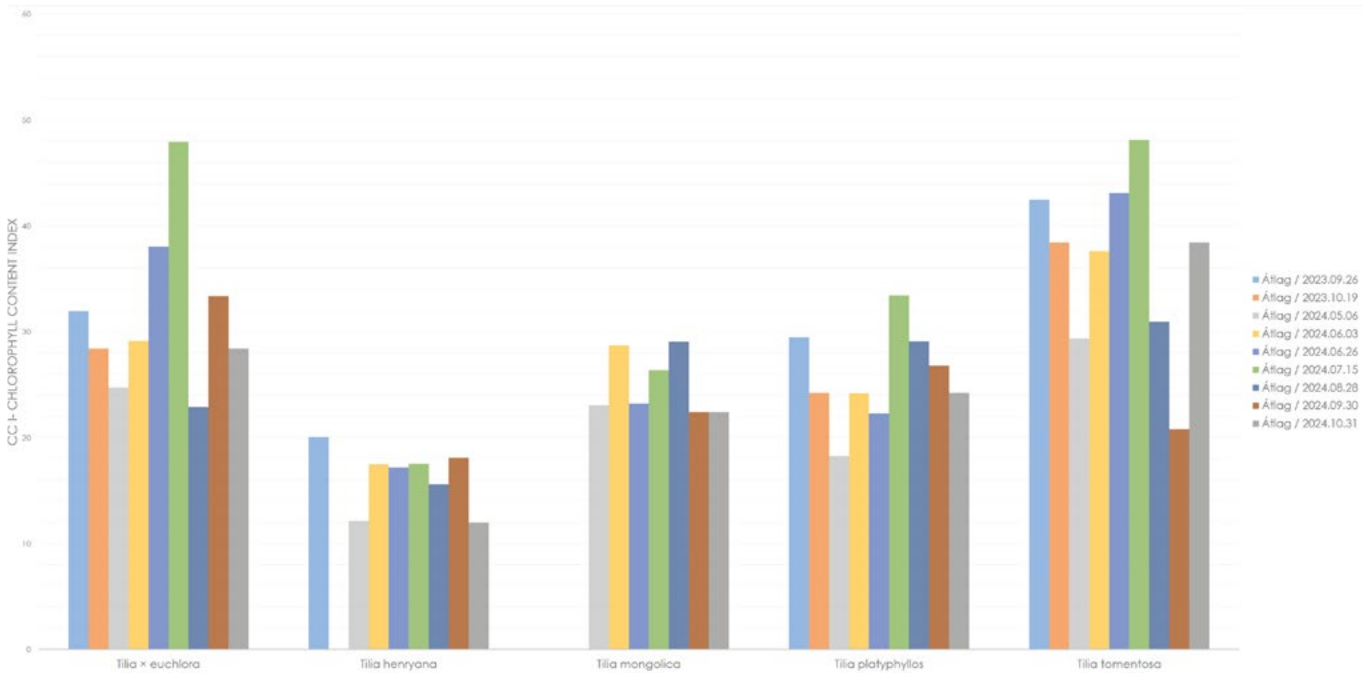
Figure 4: Chlorophyll content of the genus Tilia



SUMMARY

Based on our measurements so far, it can be concluded that a comprehensive assessment requires the comparison of data from several growing seasons. Measurements should be made at least once every month, but in the middle of the growing season, due to the differences between the values at the beginning and the end of the month, it may be advisable to include two measurements in order to assess the extreme values in relation to the weather conditions. Chlorophyll values for the 2024 growing season clearly show that the chlorophyll content of most species reaches its maximum in July. Without comparing meteorological data, it is not possible to draw a precise conclusion about the fluctuations in the following period or to determine whether this is a decline in production or a consequence of the dry weather in August and September.

The latter result was also obtained in a study by Aliya Khuzhakhmetova (2023), where the results showed that temperatures above 30 degrees Celsius affect the intensity of photosynthesis, and that longer exposure to higher temperatures (35–38 °C) leads to the destruction of the photosynthetic apparatus due to the inactivation of enzymes and the damage of membranes (Khuzhakhmetova et al., 2023).

In the continuation of the research, we will compare the chlorophyll data with the weather data to better evaluate the measurement results and will complement this with a study of the additional ecosystem services of the selected species. We also plan to measure cooling capacity, photosynthetic activity and to evaluate the canopy cover of taxa according to an RGB-based vegetation index (Bodor-Pesti et al., 2025). ⦿

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