



Chlorophyll concentration analysis of woody plants in the Buda Arboretum

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Abstract: Urbanization and climate change challenge the sustainability of green infrastructure. Woody species play a key role by providing various ecosystem services, though their contributions differ. Our research aims to identify high-performing taxa. In the first phase, we measured the leaf chlorophyll content of nearly 70 taxa in the Buda Arboretum using the Apogee MC-100. Chlorophyll levels increased until July and then declined. Significant differences were observed between young and mature leaves, and among genera. Abiotic factors also influenced values. Results indicate that reliable assessment requires data from at least 3–4 growing seasons with monthly, or mid-season bi-monthly, measurements.

Keywords: chlorophyll content, photosynthetic activity, urban forestry, ecosystem service, plant application

1. Introduction

In contemporary urban environments, both abiotic (e.g. temperature fluctuations, air pollution) and biotic factors (e.g. the proliferation of invasive species, pathogens, and pests) exert increasing influence on urban ecosystems, with tangible impacts on daily human life [1].

Amidst this rapidly transforming context, urban green infrastructure – comprised of interconnected elements such as tree lines, green corridors, and woodland patches – plays a pivotal role. These green areas not only serve aesthetic and recreational purposes but also function as vital ecological corridors that contribute to environmental regulation, urban microclimates, and the visual character of cities [2–6].

Woody plant taxa are core constituents of urban ecosystems and hold exceptional importance due to their longevity and biomass, which allow them to deliver critical ecosystem services [5, 7]. These include carbon sequestration, oxygen production, hydrological regulation, soil stabilization, support for biodiversity, and contributions to human well-being through visual and recreational value [8]. The selection of species for urban planting must consider their environmental adaptability and resilience to pests and diseases [9–14]. Previous studies have identified leaf chlorophyll content as a reliable proxy for photosynthetic efficiency, correlating directly with oxygen production and the mitigation of climatic stressors [4, 15–17].

To address the challenges posed by climate change and intensifying urbanization, our ongoing work focuses on identifying woody species best suited for urban conditions and delivering high-value ecosystem services. We target both currently utilized and underrepresented taxa in cities, aiming to expand the species palette with individuals that demonstrate resilience and functionality. This interdisciplinary research relies on advanced measurement techniques and modelling approaches, which, as Hirabayashi (2022) notes, enable more precise quantification of ecosystem services [18–21]. The insights gained can inform more sustainable urban planning, resource management, and climate adaptation strategies.

By correlating in-situ chlorophyll data collected throughout the growing season with meteorological records, we aim to better understand how environmental variables influence chlorophyll synthesis across different taxa and cultivars. Species diversity in urban tree populations is a cornerstone of long-term resilience, and future research may prioritize the integration of taxa from warmer USDA hardiness zones (8a–b).

Our preliminary investigations concentrate on one specific plant functional trait – leaf chlorophyll content – as a measurable indicator of ecosystem performance. Since chlorophyll concentration varies by species and over time [22, 23], its monitoring across phenological stages allows us to explore seasonal dynamics. Furthermore, our study includes comparisons of chlorophyll levels in juvenile versus mature foliage of evergreen species, offering additional insight into intra-species physiological variation.

2. Materials and methods

A total of 101 woody taxa from the Buda Arboretum collection were selected for evaluation. The selection process was based on the species listed in the Inventory of Public Trees (2022) [24], supplemented by additional tree and shrub taxa with potential applicability found in relevant literature [11, 16, 25–28]. Chlorophyll content was measured across nine sampling events beginning in September 2023. Of the selected taxa, 50 were included in the 2022 revised Inventory, while 51 represented additional shrub and tree species tested (*Fig. 1*).

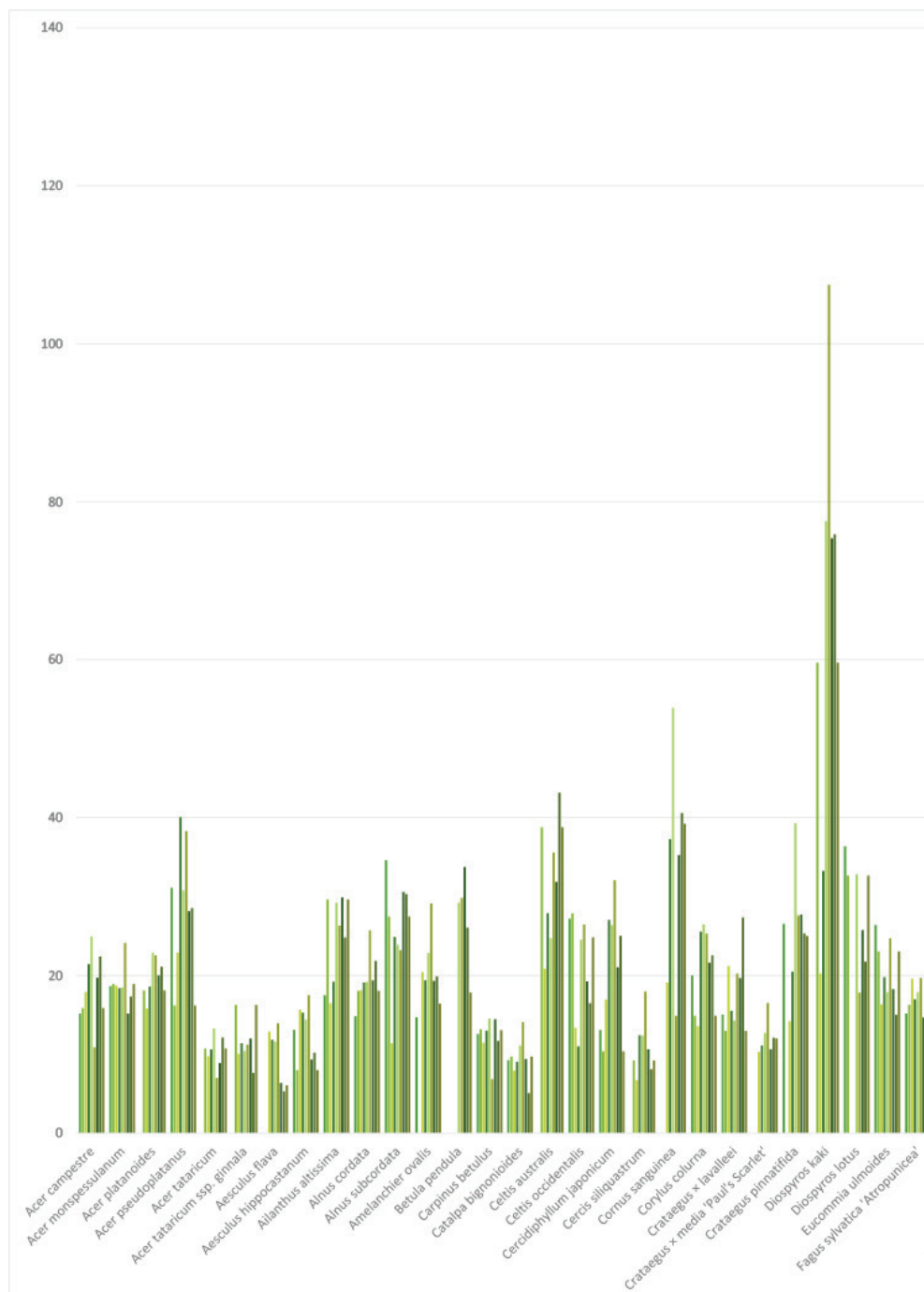


Figure 1a. CCI values of the studied woody plants

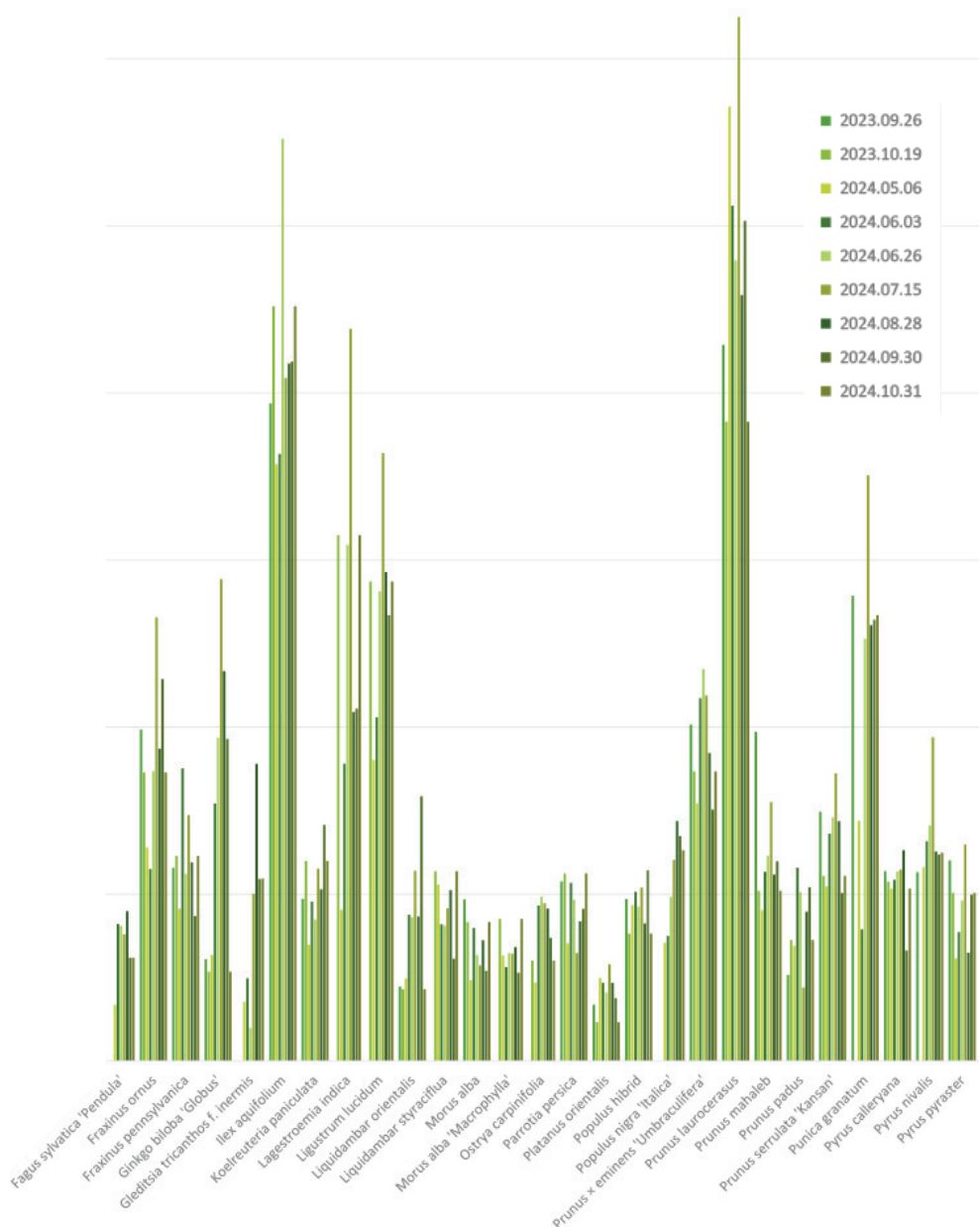


Figure 1b. CCI values of the studied woody plants

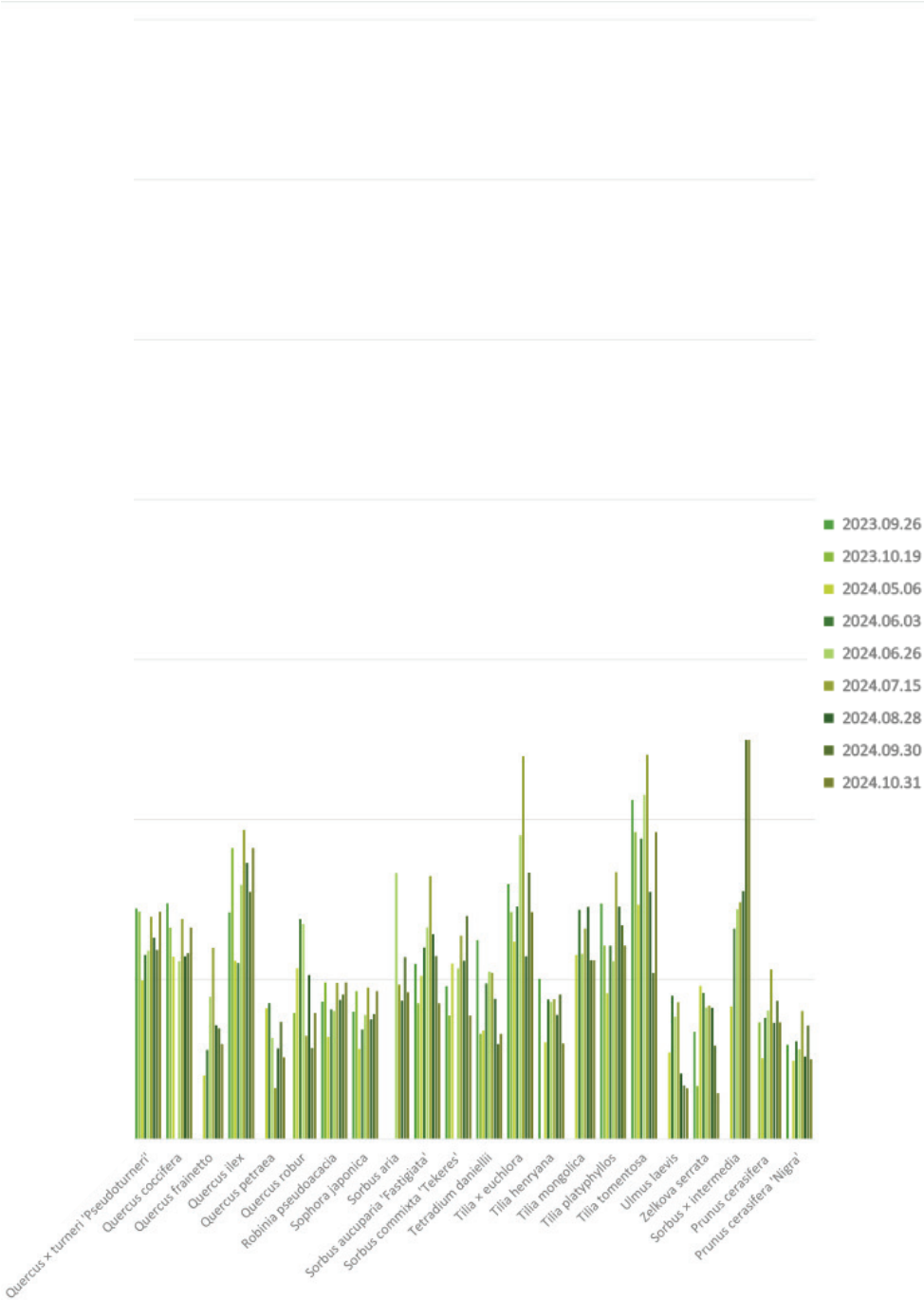


Figure 1c. CCI values of the studied woody plants

The study site, the Buda Arboretum, is situated in the southeastern section of the Buda Hills, at the transitional boundary between upland and lowland climatic zones. The area receives an average annual precipitation of 600–620 mm. Soils are moderately to highly calcareous, alkaline (pH ~8.0), and low in humus content. During the study period (autumn 2023 to autumn 2024), climate records indicated that the autumn and winter of 2023/2024, as well as the spring of 2024, were the warmest on record since 1901. The growing season commenced earlier than usual, beginning in February/March. The seasonal average temperature in Budapest (15 °C) exceeded the 1991–2020 multi-year average (11.1 °C) by 3.9 °C. Precipitation ranged between 120 and 140 mm and was highly uneven in distribution [29].

Chlorophyll content was assessed using the Apogee Instruments® MC-100 (S/N:1999, USA), a device designed for rapid, non-destructive field measurements. This instrument determines leaf chlorophyll content via optical reflectance by emitting light at 635 nm (red) and 700 nm (infrared) wavelengths. Reflectance values are then used to compute the Chlorophyll Content Index (CCI), a dimensionless parameter developed by CIRAD. Although the CCI does not yield absolute chlorophyll concentrations (e.g. µg/cm²), it provides reliable relative values that are suitable for interspecific and seasonal comparisons [30–33]. This makes the MC-100 particularly effective for long-term monitoring and comparative field studies.

Samples were collected from the ground level, targeting sun-exposed (light) leaves from the outer canopy. For deciduous species, 10 samples were taken per individual, and for evergreen taxa, 5 samples per taxon were collected. Juvenile and mature leaves were sampled separately. Preliminary results were analysed and visualized using charts generated in Microsoft Excel (Version 2407).

3. Results and discussions

Over the course of nine measurement periods, chlorophyll values exhibited a consistent upward trend until June, peaking in July. Following this, a general decline in CCI values was observed among most deciduous taxa. Evergreen species also reached their highest chlorophyll levels in July; however, after a decline in August, a slight resurgence was noted in the September and October measurements. CCI values across evergreen and deciduous taxa – including species that either shed their leaves slowly or retain them through milder winters – ranged widely from 11.5 to 175.1. The highest value was recorded on *Diospyros kaki* in July.

Among the taxa listed in the *2022 Inventory of Public Shrubs and Trees*, genera such as *Prunus* and *Tilia*, as well as the cultivar *Ginkgo biloba* ‘Globus’, exhibited notable values, averaging 35 CCI in June 2024. In July, *Fraxinus ornus* (53.1), *Ginkgo biloba* ‘Globus’ (57.7), *Prunus* × *eminens* ‘Umbraculifera’ (43.8), *Tilia* × *euchlora* (47.9), and *Tilia tomentosa* (48.1) recorded the highest readings.

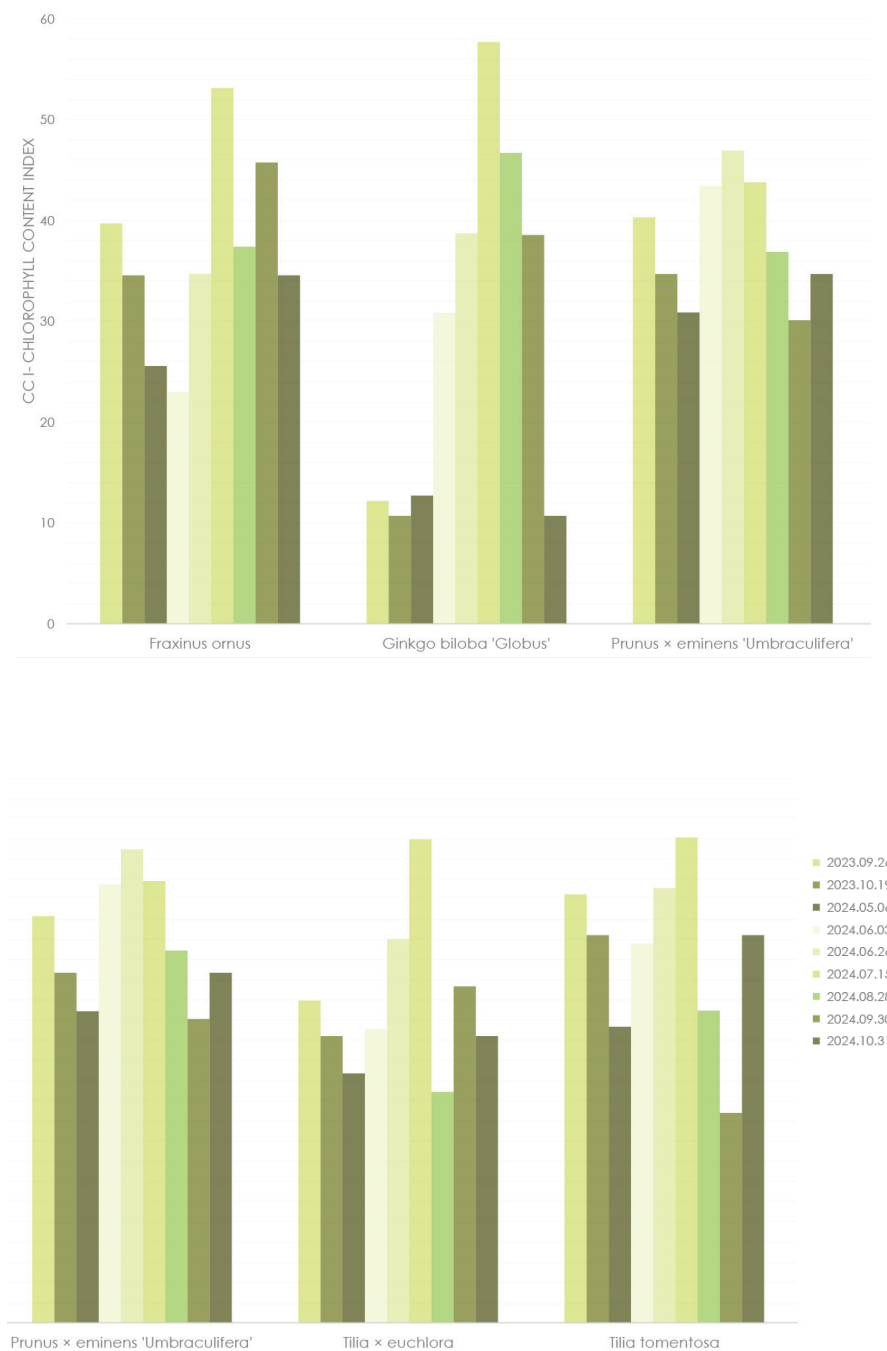
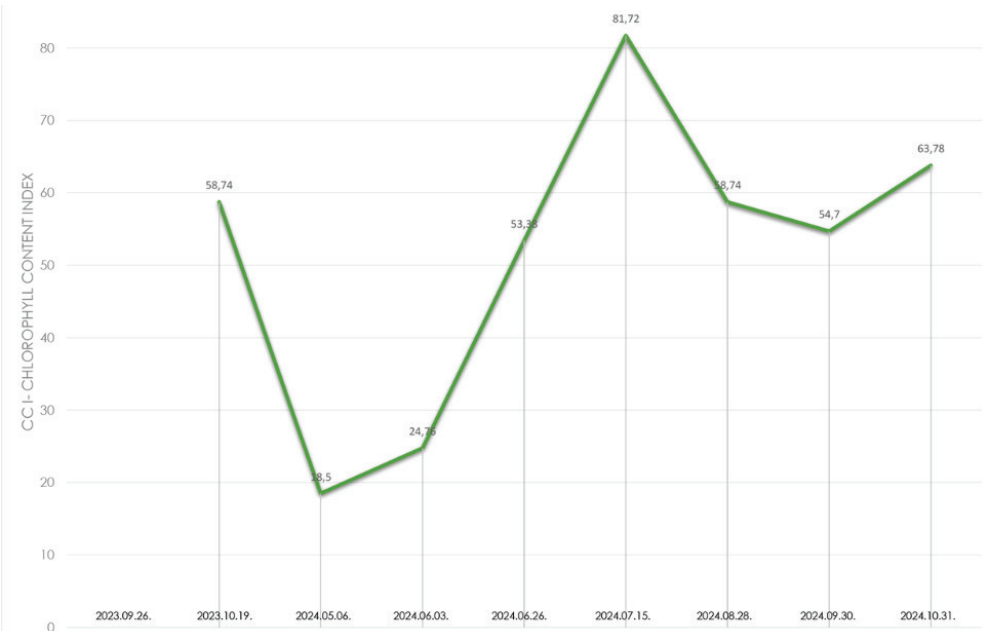
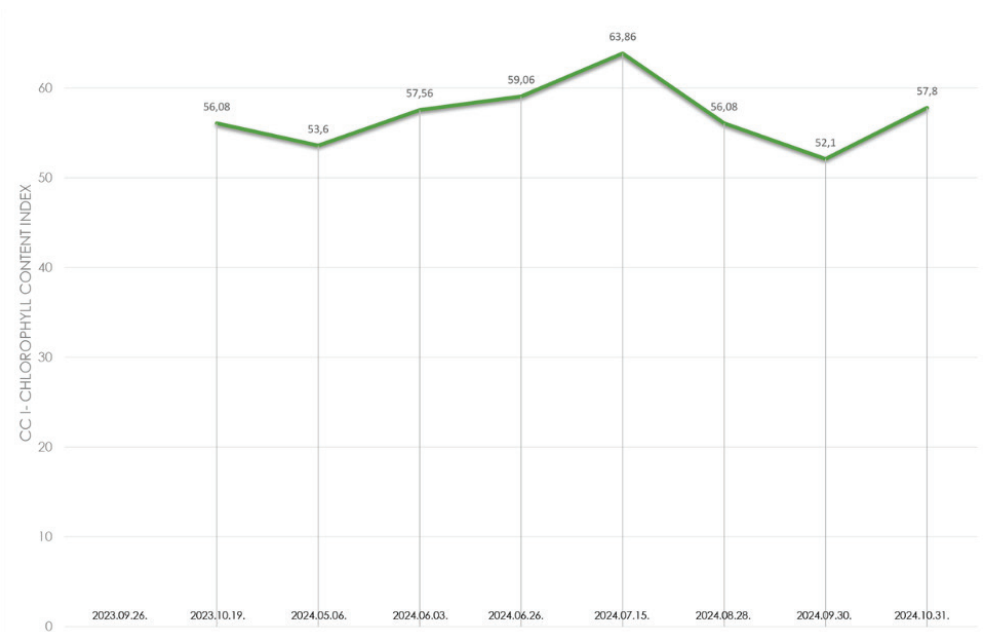


Figure 2. Top performing tree taxa by chlorophyll content index in the summer of 2024 (based on the 2022 Inventory of Public Trees)



(a)



(b)

Figure 3. Comparison of the chlorophyll levels in young (a) and old (b) leaves of *Ligustrum lucidum*

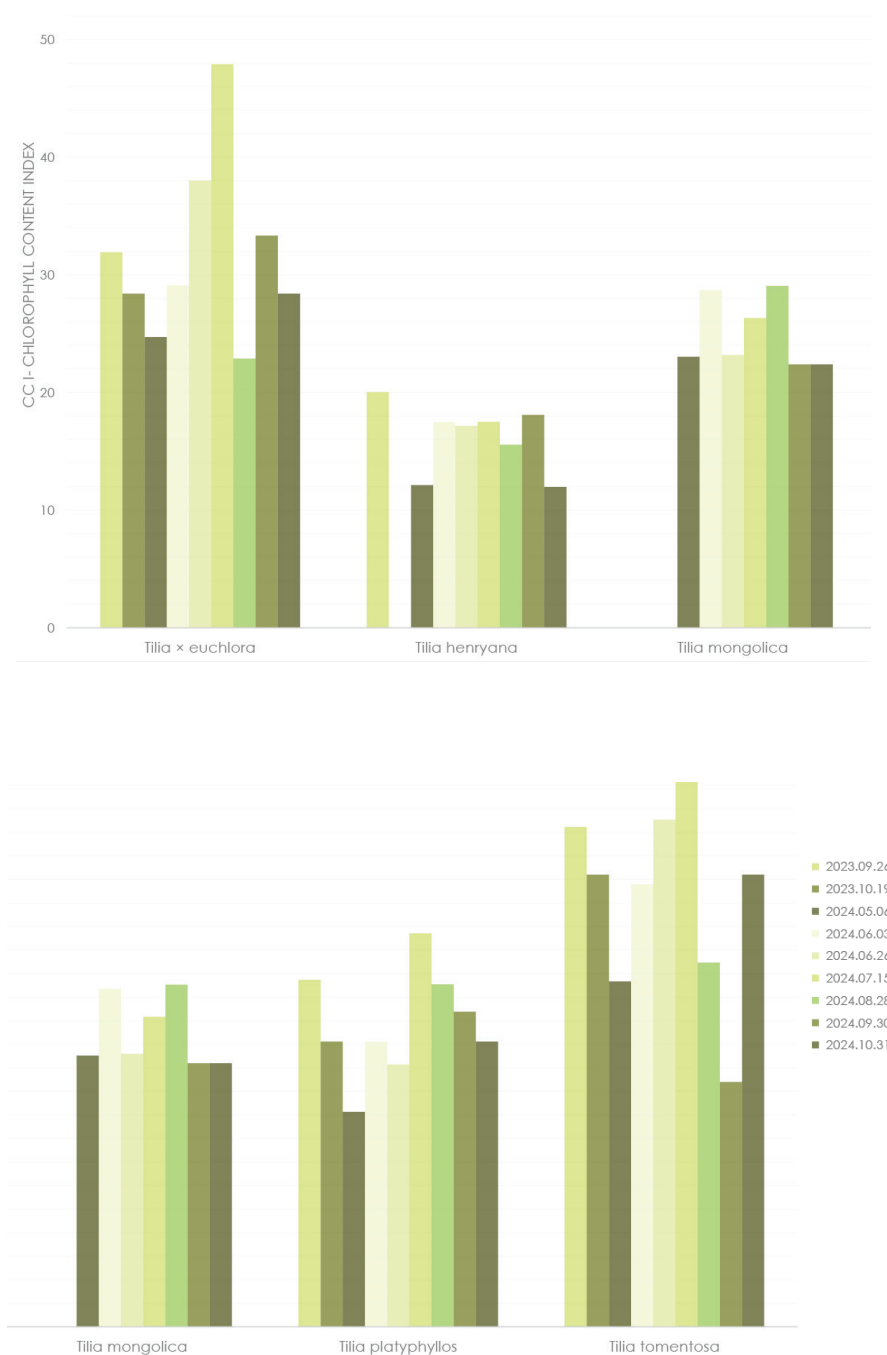


Figure 4. Chlorophyll content of the genus *Tilia* spp.

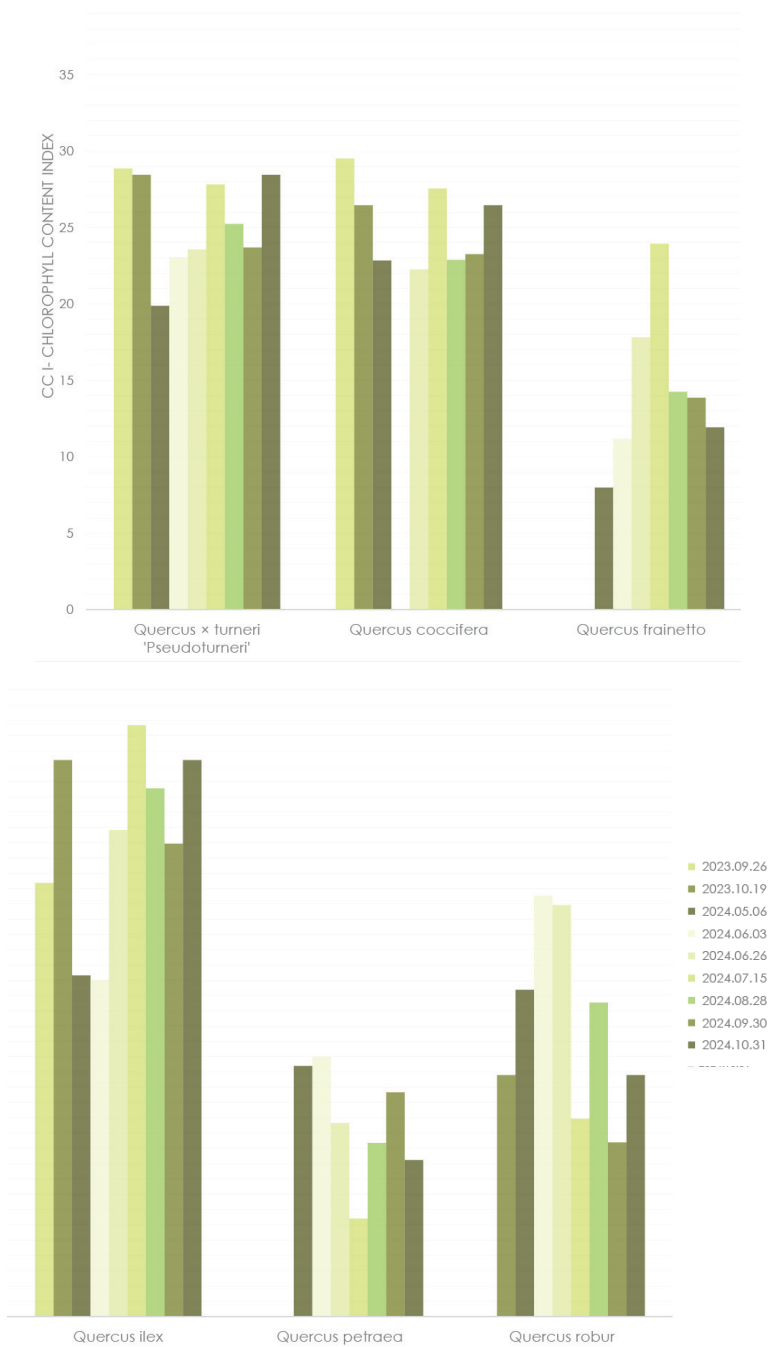


Figure 5. Chlorophyll content of the genus *Quercus* spp.

Among the unlisted taxa, the highest peak values were observed in *Diospyros kaki* (107.5), *Lagerstroemia hybrid* (87.7), *Ligustrum lucidum* (72.8), and *Punica granatum* (70.1). Chlorophyll values of juvenile leaves across both evergreen and deciduous species displayed wide variability, ranging from 11.5 to 175.1. These values increased steadily until July, followed by divergent trends from August to October.

In contrast, values measured on older leaves varied less, ranging from 17.9 to 136.7. In evergreen *Quercus* species, no significant difference was detected between juvenile and mature leaves. This was also true for *Quercus* × *turneri* ‘*Pseudoturneri*’. *Ligustrum lucidum* juvenile leaves showed a post-July decline following their peak (81.7), with subsequent values of 58.7, 54.7, and 63.7. Meanwhile, older leaves of this species exhibited a narrower range (52.1–63.8) (Fig. 4). Generally, juvenile leaves exhibited higher chlorophyll values than older leaves by June and then gradually declined, eventually converging with the older leaf values. Most taxa reached this point of convergence between the 25th and 30th week (Fig. 3).

Substantial interspecific variation was also observed within genera. Among the six *Acer* species evaluated, *Acer pseudoplatanus* showed the highest values, while *A. tataricum* (7.0–13.2) and *A. tataricum* subsp. *ginnala* (7.6–16.2) recorded the lowest. Within the *Prunus* genus, *Prunus* × *eminens* ‘*Umbraculifera*’ had the highest chlorophyll content (30.1–46.9), followed by *P. mahaleb* (18.0–39.4) and *P. serrulata* ‘*Kanzan*’ (20.1–34.4), both exceeding average values. Among *Tilia* species (Fig. 4), *T. tomentosa* (20.8–48.0) and *T.* × *euchlora* (22.8–47.9) showed the highest chlorophyll levels, while *T. henryana* (12.1–20.0) consistently remained below 20 CCI.

Among evergreen oaks, *Q. ilex* recorded the highest chlorophyll values (22.0–38.6), while *Q.* × *turneri* ‘*Pseudoturneri*’ (19.8–28.8) and *Q. coccifera* (22.2–29.5) produced nearly identical readings. Interestingly, the June values of deciduous *Q. robur* (27.5 and 26.9) exceeded those of the two evergreen oaks measured during the same period. The lowest readings across all *Quercus* species were recorded for *Q. petraea* (6.4–17.0), potentially attributable to severe powdery mildew infection (Fig. 5).

4. Conclusions

Based on the measurements conducted thus far, it can be concluded that a comprehensive evaluation necessitates the comparison of data spanning multiple growing seasons. Monthly measurements are essential; however, during the peak of the growing season, bi-monthly sampling may be advisable due to significant intra-month variability, particularly at the beginning and end of each month. This approach would allow for a more accurate detection of extreme values in relation to prevailing meteorological conditions. Data from the 2024 growing season clearly indicate that chlorophyll content in most taxa peaks in July. However, in the absence of concurrent meteorological data, it remains difficult to determine whether subsequent fluctuations are due to physiological declines in chlorophyll production or are the result of drought stress during August and September.

Similar findings were reported by Aliya Khuzhakmetova (2023), who demonstrated that air temperatures exceeding 30 °C negatively impact photosynthetic efficiency and that prolonged exposure to higher temperatures (35–38 °C) can lead to structural damage to the photosynthetic apparatus, primarily due to enzyme inactivation and membrane degradation [34].

In the next phase of our research, we intend to correlate chlorophyll data with detailed weather records to enhance the interpretive accuracy of our results. This will be complemented by an assessment of additional ecosystem services provided by the selected taxa. Future investigations will focus on the combined evaluation of photosynthetic activity, transpiration measurements, and RGB-based canopy analysis to obtain a more complex understanding of the taxa's performance under urban environmental conditions [23].

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