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## THE SENSITIVITY OF HERBACEOUS PLANTS TO LIGHT POLLUTION

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### Abstract

Plants living near street lights in temperate zones are good examples of the effect of light pollution with a marked shift in leaf fall and bud breaking. Low intensity light (light pollution) is not sufficient for photosynthesis, but can cause changes in many physiological processes, moreover, it can have a disrupting effect on the plant and its connected ecosystem. In this study, physiological effects of light pollution on leaf morphology, leaf anatomy, and photosynthesis were investigated in the herbaceous species *Erigeron annuus* (L.) Pers. and *Fallopia x bohémica* (Chrtek et Chrtková) J.P. Bailey under conventional HPS and LED illumination. In our experience, HPS lamps supported the photosynthetic activity of the studied species, the growth of palisade tissue cells. Light pollution of LED lamps reduced net photosynthesis in both species compared to non-light-polluted leaves.

**Key words:** *light pollution, Erigeron, Fallopia, morpho-anatomy, photosynthetic activity*

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## A LÁGYSZÁRÚ FAJOK ÉRZÉKENYSÉGE A FÉNYSZENNYEZÉSRE

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### Összegzés

A mérsékelt égövi utcai lámpák közelében élő növények a fényszennyezés hatását jól szemléltetik a levélhullás és rügyfakadás szembetűnő eltolódásával. A gyengébb intenzitású fény nem elegendő a fotoszintézishez, de számos élet-tani folyamat megváltoztatását idézheti elő, zavart okozva a növény és a vele kapcsolatban álló élőlények életében is. Vizsgálataink során az *Erigeron annuus* (L.) Pers. és a *Fallopia x bohemica* (Chrtek et Chrtková) J. P. Bailey lágyszárú fajok fényszennyezésre bekövetkező levélmorfológiai, levélanatómiai és fotoszintézis élettani változásait vizsgáltuk hagyományos HPS- és LED-megvilágítás mellett. A HPS-lámpák tapasztalataink szerint támogatják a vizsgált fajok fotoszintetikus aktivitását, a paliszád szövet sejtjeinek növekedését. A LED-lámpák fényszennyezése mindkét faj esetében csökkentette a nettó fotoszintézist a nem fényszennyezett levelekhez képest.

**Kulcsszavak:** *fényszennyezés, Erigeron, Fallopia, morfo-anatómia, fotoszintetikus aktivitás*

## Introduction

In the natural rhythm of life on earth, darkness at night means calmness, regeneration, rest for most living beings, while for others it means activity. This alternating rhythm determines the normal cycle of life. In the civilized world, at many locations, artificial light at night disturbs this natural rhythm by eliminating the dark period. But what does artificial light at night mean for photosynthesizing organisms? For the vast majority of plants, light means life, regardless of its source, if its intensity is high enough for assimilation to take place.

Plants also sense the length of dark and light periods, which are used to regulate their internal processes (KROONFELD-SCHOR and DAYAN, 2003; GERRISH et al., 2009). Although lower intensity light is not sufficient for photosynthesis, it can alter the plants' physiological processes, especially in plants where timing of their bud breaking, flowering, ripening, and dormancy periods are based on the light and dark cycle. One of the striking effects of artificial light is observed mainly in temperate plants, where light-sensitive receptors (red - distant red receptors) of trees near street lamps are deceived by light pollution, thus the days are perceived to be longer, causing leaf fall to be delayed, even to December. Consequently, the plant cannot prepare for the cold period, it can fall victim to frost and ice damage. Light pollution can also have an effect in the spring, causing early bud breaking and flowering, endangering the reproductive success of the plants by the disruption of their coordinated relationship with frost effects or with pollinating insects. In the present study, as continuation of our preliminary methodological experiments, we followed the physiological changes in leaf morphology, anatomy and photosynthesis in herbaceous species during two consecutive years.

## Literature review

Research shows that light pollution affects plant leaf growth, increases the number of stomas and influences the opening of the stomas as well, which can interfere with the regulation of evaporation and thus with drought tolerance (CHANEY, 2002). The susceptibility of open somas to air pollution can thus increase, which can cause further changes in plant physiology. Photobiological processes in plants are regulated by visible light supporting the process of photosynthesis (400–450 nm and 625–700 nm), and light in the visible red (625–760 nm) and infrared (760–850 nm) spectrum through the photosensitive pigments (e.g. phytochromes). In addition to wavelength, the intensity and duration of the illumination determine the processes influenced by light in plants (CHANEY, , 2002). Light pollution at night provides almost continuous (day and night) illumination for the plant. Studies have shown that in the case of *Panax notoginseng*, subjected to continuous and high intensity light, the leaves shrank, the stomas closed and the net photosynthesis of the plant decreased. Normal plant

growth was successful only with shading (Li et al., 2009). Several studies have shown that continuous periods of darkness are critical for certain processes controlling repair and recovery of physiological functions in many species, and therefore darkness can be considered as a source of physiological activity (GASTON et al., 2013). For example, VOLLSNES et al. (2009) demonstrated that light during Arctic summer nights inhibits recovery from leaf damage caused by atmospheric ozone in subterranean clover *Trifolium subterraneum*, and in *Arabidopsis thaliana* QUEVAL et al. (2007) showed correlation between day length and the rate of oxidative cell death.

In angiosperm plants, the synthesis of photosynthetic pigments (chlorophylls) occurs only under photosynthetically active radiation (PAR) at wavelengths between 400 and 700 nm (REINBOTHÉ et al., 1996). The intensity of the light is strongly correlated with the amount of the incorporated CO<sub>2</sub>. The intensity of light pollution at night is typically less than 0.5  $\mu\text{molm}^{-2}\text{s}^{-1}$ , extremely low compared to daylight (100–2000  $\mu\text{molm}^{-2}\text{s}^{-1}$ ), so the impact of light pollution on net carbon incorporation is likely to be negligible in most cases (MERAVI and PRAJAPATI, 2018).

Woody plants (65 species) were separated into high, medium, and low sensitivity groups by CHANEY (2002) according to the sensitivity of their internal biological clock to red and infrared light pollution (bud break, flowering induction, dormancy). For many species of trees in the streets, nocturnal light pollution reduces plant photosynthesis (MERAVI and PRAJAPATI, 2018). The maximum photochemical quantum yield (Fv/Fm) of Photosystem II is decreased, which is also an indicator of the stress level of the plants. In addition to the physiological effects on the plants, light pollution can also upset the balance of the ecosystem, as plants that can take advantage of growth-inducing effects of artificial lighting can suppress their peers, thus changing the composition of the ecosystem (NAVARA & NELSON 2007). Changes in the physiology of plants can also cause disturbances in the food chains built on them and in the relationship of the animals involved in it, as well as in the feeding and hiding opportunities of insects and birds (NAVARA and NELSON, 2007).

## Materials and methods

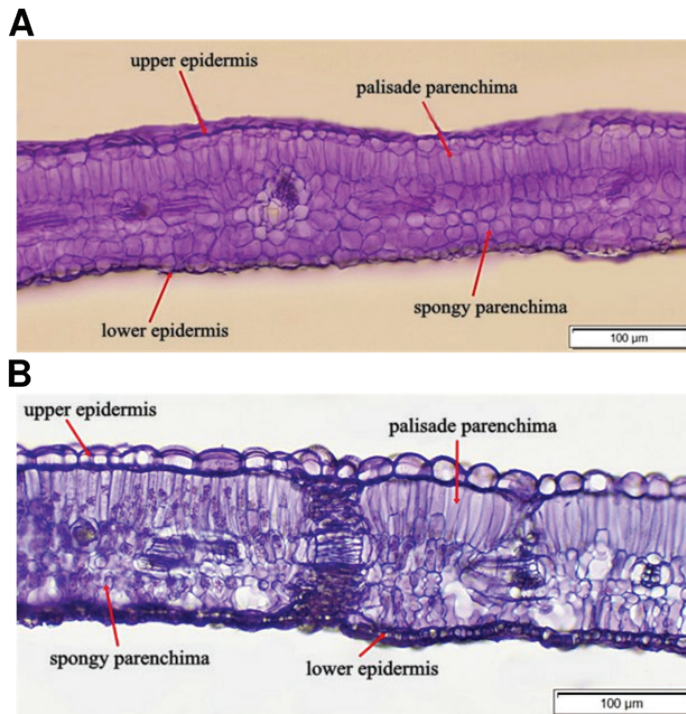
In the present work, the herbaceous, not very selective *Erigeron annuus* (L.) Pers. and the also invasively expanding *Fallopia x bohémica* (Chrtek et Chrtková) J.P. Bailey species were studied. Our morpho-anatomical and photosynthetic physiological studies were performed for two years, in 2018 and 2019. Leaf samples were collected in Bárdudvarnok, Hungary, located near the border of The Zselic Park of Stars.

Observations and measurements were made on 10 fully developed, healthy, similarly orientated leaves of the plants. Three plants were selected in each locations, there were 3 separate locations. Histological examinations were per-

formed on 2 leaves obtained from 2 plants from the 3 locations. Photosynthesis was studied by measuring net photosynthesis with a LICOR 6400 device. Pulse-Amplitude-Modulation fluorometry was used to obtain quantitative information on the quantum yield of photosynthetic energy conversion. The leaves were dark adapted for 20 min before measurement, then the level of measurement light (80 PAR) was maintained for 20 s and fluorescence was measured before ( $F_0$ ) and after ( $F_m$ ) a saturation flash. The maximum quantum efficiency of photosystem II (PSII) was calculated as  $F_v/F_m = (F_m - F_0)/F_m$  according to BJÖRKMAN and DEMMIG (1987). In the first year we studied individuals living under traditional (HPS) street lighting, in the following year we examined and compared the shoots of the same individuals developed under LED lights. The Past program (HAMMER et al., 2001) were used for statistical analysis. Data were expressed as mean  $\pm$  SD. Student's t-test were used for statistical comparisons.

## Results

The leaves of *Erigeron annuus* (Fig. 1A) and *Fallopia x bohémica* (Fig. 1B) have a typical dorsiventral heterogeneous mesophyll structure. in *Fallopia x bohémica*.



**Figure 1.** Cross sections of light- and non-light-polluted leaves.

A) Cross section of light polluted leaf of *Erigeron annuus* (2018). B) Cross section of non-light polluted leaf of *Fallopia x bohémica* (2019).

Below the cuticle-covered ventral epidermis is a one-layer columnar parenchyma. On the dorsal side, the mesophyll of the epidermis is formed by a multilayered spongy tissue, which is dense in *Erigeron annuus* and loose with many intercellular passages in *Fallopia x bohémica*.

Both the length (significantly) and the leaf thickness of the palisade cells of the species *Erigeron annuus* increased as a result of the light pollution of the HPS lamps (2018). However, with LED lamps (2019), all this could not be observed, in this case the length of the palisade parenchyma cells and the leaf thickness of the non-light-polluted leaves showed significantly higher values (Table 1).

In the case of *Fallopia x bohémica*, light polluted of both HPS and LED lamps significantly increased the length of the palisade cells and the thickness of the leaf.

		Erigeron annuus	
		light polluted	non-light-polluted
2018	leaf thickness ( $\mu\text{m}$ )	299,1+16,9***	184,9+6,6
	length of palisade cells ( $\mu\text{m}$ )	67,6+7,1	42,4+4,8
2019	leaf thickness ( $\mu\text{m}$ )	150,2+27,9***	175,1+6,3
	length of palisade cells ( $\mu\text{m}$ )	32,7+3,8***	45,8+6,9

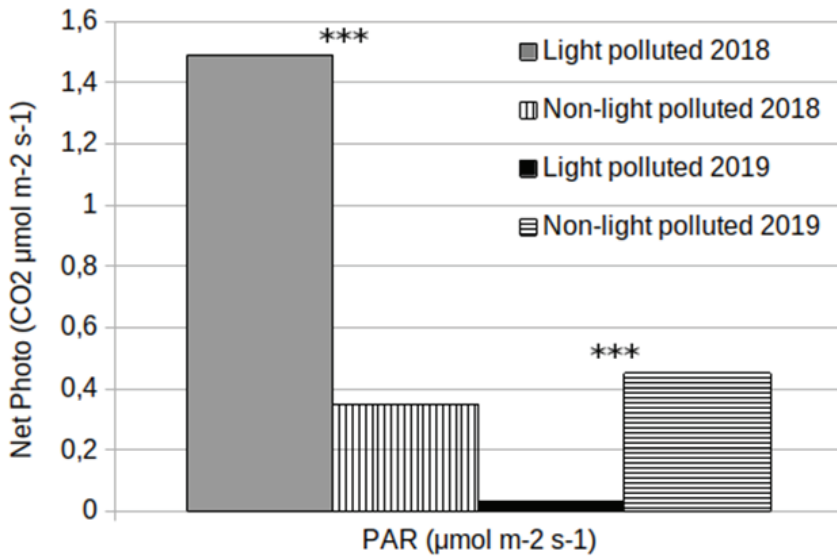
**Table 1:** Length of palisade parenchyma cells and leaf thickness in light-polluted and non-light-polluted leaves

Based on the length and width of the leaves, light pollution of HPS and LED lamps did not cause a significant increase in leaf surface area (Table 2).

	light polluted			non-light-polluted		
	leaf length (cm)	leaf width (cm)	length/width (ratio)	leaf length (cm)	leaf width (cm)	length/width (ratio)
2018 (HPS)	17,57+1,45	12,18+2,08 **	1,56+0,84	18,15+1,86	13,05+1,30	1,40+0,13
2019 (LED)	19,09+1,18**	15,93+1,62	1,21+0,12**	19,93+1,49	15,81+1,78	1,27+0,11

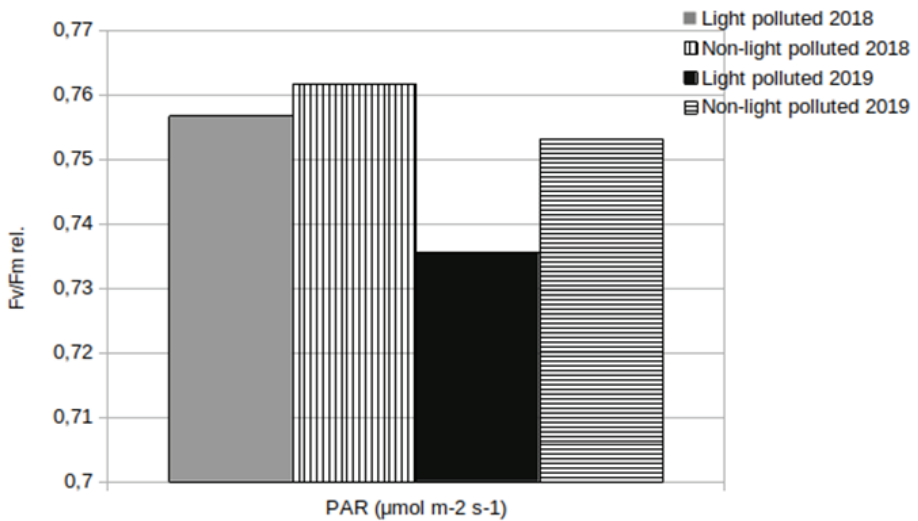
**Table 2:** Morphometric characteristics of *Fallopia x bohémica* leaves under HPS (2018) and LED (2019) illumination (Legend \*\*:  $P < 0,05\%$ )

Concerning the net photosynthesis of *Erigeron annuus*, photosynthetic activity of leaves light-polluted by HPS lamps were higher than the control. However, after lamp replacement, under LED lamps, the net photosynthesis of non-light-polluted leaves was significantly higher for both species (Fig. 2).



**Figure 2.** Net photosynthesis of *Erigeron annuus* in a light-polluted and non-light-polluted environment under HPS (2018) and LED (2019) lighting (Legend \*\*\*:  $P \leq 0,01\%$ )

Both the maximum photochemical quantum yield ( $F_v / F_m$ ) of photosystem II and net photosynthesis decreased for *Fallopia x bohémica* due to light pollution by LED lamps, however, there was no detectable difference in the case of HPS illumination (Fig. 3).



**Figure 3.** Maximum quantum yield of photosystem II of *Fallopia x bohémica* in light-polluted and non-light-polluted environments under HPS (2018) and LED (2019) illumination.

## Discussion

The studied species have a wide environmental tolerance and are invasive in Hungary. According to the relative light requirements of *Erigeron annuus*, it can be classified mainly into the group of semi-shade plants (PÁL, 2012), *Fallopia x bohemica* grows well in areas without cover, in semi-shade or in the forest in shady places (BALOGH, 2012). Although the illumination spectra of HPS lamps does not cover the full wavelength range of photosynthesis, in our experience it supports the photosynthetic activity of the studied species and the growth of palisade tissue cells, which play a key role in leaf photosynthesis, thus increasing plant biological production. Light pollution of LED lamps, according to our studies, inhibits the development of the monophylum of *Erigeron annuus* leaf (thinner leaf, shorter palisade cells) (Table 1), and reduces its net photosynthesis compared to leaves developing under normal conditions. Although LED light pollution in *Fallopia x bohemica* significantly increased leaf thickness and supported photosynthetic palisade cell growth, but similarly to *Erigeron annuus*, it reduced net photosynthesis and the maximum quantum yield of photosystem II. This also suggests high plant stress level, which is supported by the observation that *Fallopia x bohemica* ventral epidermal cells were thicker in LED light-polluted leaves, which might serve protection against stress. Based on our results, LED lamps do not help the expansion of the studied invasive species in the living environment.

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