Final Reports
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Functionality of urban ecosystem: ecology, urban green area and air quality

Introduction

Rapid urbanization and anthropogenic activities have resulted in the emission of several pollutants. Therefore, the monitoring of urban air and the assessment of environmental risks is necessary in urban habitats Plants are especially useful as biological indicators to assess air pollution because of their wide distribution. Several plant species have already been applied as bioindicator. Heavy metals and inorganic contaminants can be emitted into the environment by transportation, industry, fossil fuels. The settling contaminants can deposit on the surface of leaves from air, and increase their harmful effects on human health (Çelik et al., 2005). Leaves are sensitive and highly exposed to air pollution. Thus, in many studies tree leaves were used as indicators to assess the quality of air in urban environments. Leaves can trap various airborne particles such as trace elements, pollens, spores and salts. Thus, they are good accumulators of atmospheric contaminant (Prusty et al., 2005). The capacity of leaves as dust trap depends on such factors as surface geometry, phyllotaxy, epidermal and cuticular features, leaf pubescence, and height and canopy of trees. Leaves collect dust on their leaf surface and trichomes. They could absorb gaseous pollutants via their stomata which interact between plants and their environment in this aspect leaves are active air contaminant collectors. On the other hand, leaves collect and deposit dust via their trichomes; thus, they are also passive dust traps (Singh et al., 2005). Thus, tree leaves are widely studied bioindicators of air pollutants (Simon et al., 2014).

In our project the main hypothesis and aims were the followings: (i) validation and air pollution assessment method based on leaves, (ii) our hypothesis was that the particle size of deposited dust is generally lower than 10 μm, (iii) our hypothesis was that the Air Pollution Tolerance Index (APTI) was useful tool to assess the level of air pollution based on tree species, (iv) our hypothesis was the Air Pollution Tolerance Index (APTI) of tree species, the amount of dust and trace element concentrations in deposited dust and leaves is higher in the those area in cities where the traffic and industrial activities are more intense, (v) we hypothesized that the weather factors might modify the level of air pollution and we will study the seasonal patterns of air pollution based on the Air Pollution Tolerance Index (APTI) of tree species, particle size distribution of deposited dust and trace element concentration in deposited dust and tree leaves in the second largest city , in Debrecen in North-East Hungary, (vi) we hypothesized that our hypothesis was that different species vary considerably in their susceptibility to air pollutants. The native tree species (*Acer sp., Fraxinus excelsior, Tilia sp.*) are less tolerant of air pollutants, than non-native tree ones (*Celtis occidentalis, Robinia sp.*)

Results

Results of validation and air pollution assessment method, particle size distribution based on leaves (i and ii hypothesis)

According to the work plan of project we studied as validation method the different types (PM_5 and PM_{10}) of dust contents on tree leaves. Common Lime (*Tilia europaea*) was chosen to collect leaf samples and particulate material samples with trapping in three summer months of 2018 in the campus of the University of Debrecen, Hungary. In every month 60 leaves were collected from two different heights (1.80 and 3.60 m) in three replicates. Leaves were pooled before the analyses. Similarly, to the leaves, particulate material samples were also collected from two heights (1.80 and 3.60 m) with three replicates of the same tree.

In dust trap 95 percentage of all dust content was deposited dust (PM_{10}), while in the case of leaves 77 percentage of all dust content was deposited dust (PM_{10}). We found significant differences in the concentration of PM between tree leaves and dust traps based on the PM_{10} in each month. We also found significant differences in PM_5 between tree leaves and dust traps but only in July. Based on the concentration of PM a significant difference was found among months, based on the PM_{10} from leaves, and dust traps and PM_5 from leaves There were no significant differences in PM between sampling heights. We found a significant positive correlation in PM_{10} deposited on leaves and dust traps. There was no significant correlation in PM_5 deposited on leaves and dust traps. There was a significant positive correlation between the concentration of PM determined by gravimetric and laser diffraction methods only on leaves. There was no correlation between the PM concentration determined by gravimetric and laser diffraction methods in the case of traps (*Simon et al. Atmosphere 2020, 11, 559*).

Results of Air Pollution Tolerance Index (APTI) as a useful tool to assess the level of air pollution based on tree species (iii hypothesis)

We measured APTI of two common tree species, *Celtis occidentalis* and *Tilia sp*. from 13 locations across the city in September 2017. The 13 locations were situated across Debrecen, along a route between the western and eastern edges of the city. Each location was characterised as an urban site, as there was no industrial activity or highway with high-density traffic in the vicinity. We also compared APTI values among various cities and land use types (industrial, roadside, and urban) using robust ANOVA after data collection from earlier studies. The APTI's relationship with the population and PM_{10} (particulate matter with an aerodynamic diameter smaller than 10 μm) in cities was analysed using regression modelling and Principal Component Analysis. For statistical model building Random Forest Regression was applied.

There were significant differences in APTI values among land use types. The difference was greatest between urban (12.6 ± 3.9) and industrial (22.1 ± 8.5) areas, while there was no significant difference between roadside (15.6 ± 4.9) and urban (12.6 ± 3.9) areas. Our first hypothesis was supported APTI values of plants were higher in polluted (roadside and industrial) areas than in less polluted (urban) areas. We found a strong positive relationship between APTI values and the population size of the city ($r = 0.77$; $p = 0.017$; Fig. 4). There was a larger deviation in APTI values at smaller population sizes. The correlation with APTI values was weaker and not significant for the annual mean of PM_{10}.

According to the categorisation of Singh et al. (1991), most tree species at industrial sites are moderately tolerant, mixed with a few intermediate and tolerant species. Conversely, species in the urban areas and at roadsides were mainly sensitive and, to a lesser degree, intermediately tolerant. The rANOVA showed significant differences among cities based on APTI values. The pairwise analysis revealed that Aizawl, Bhubaneswar, Debrecen, Delhi and Jakarta had many similarities in APTI. Ahvaz differed from most of the other locations as it had the lowest APTI values. Beijing differed significantly from all the other cities (*Molnár et al. Ecological Indicators 2020, 113, 106234*).

The effect of urbanization on Air Pollution Tolerance Index (APTI) of tree species, the amount of dust and trace element concentrations in deposited dust and leaves (iv and v hypothesis)

Three sampling sites were chosen to represent the varying intensities of anthropogenic activities (urban, industrial, and rural) in Debrecen. Tree leaves from the common hackberry (*Celtis occidentalis*) and common lime (*Tilia × europaea*) were collected. There were 3 sampling stations (urban, industrial and rural).

There were significant differences in the amount of PM_5 and PM_{10} among the study sites based on *C. occidentalis*. We only found significant difference in PM_{10} on the *T. europaea* leaves. There were no significant differences in PM_5 and PM_{10} of *C. occidentalis* leaves between the studied months. There was a significant difference between the months in PM_5 deposited on *T. europaea* leaves. There was no significant difference in the amount of dust on the leaf surfaces of *C. occidentalis* and *T. europaea*. There was a significant difference along the urbanisation gradient based on *T. europaea* leaves for relative water content, the pH of the leaf, the APTI, and concentrations of Al, Ba, Cr, Cu, Fe, K, Mn, Na, Sr. The total chlorophyll and concentrations of Ba, Ca, Cr, Mg, Mn, Na, Sr of *C. occidentalis* leaves also differed significantly among sites. The parameters for *T. europaea* leaves differed between July and September, except for total chlorophyll. All parameters of *C. occidentalis* differed between months, except the concentrations of ascorbic acid ($p > 0.05$) (Table S1). The two species showed differences in many of the studied parameters in a uniform trend. Ascorbic acid content, leaf pH, relative water content and APTI itself were significantly higher in *C. occidentalis* than *T. europaea*. *C. occidentalis* scored an average APTI of 12.9 with a minimum of 8.4 and a maximum of 16.4. The average APTI of *T. europaea* was 8.7, ranging from 6.3 to 10.7 across all sites. We found significant correlations (rs) between the concentrations of manganese and PM_{10} amount; between the concentrations of manganese, and fine dust amount; and between the concentrations of chromium and manganese, and APTI in *T. europaea* leaves. For *C. occidentalis* leaves, there was a significant correlation between the concentrations of Ca, Cr, Mg, Sr, and PM_{10} amount; between the concentrations of Ca, Cu, Mn, Na nd PM_5; and between the concentrations of Ba, Cd and Na and APTI (*Molnár et al. Plants 2020, 9, 1743*).

During this project Leaf samples from *Ficus religiosa* and *Mimusops elengi* were also analysed along with topsoil samples under the selected trees. Soils were not polluted according to the critical value; furthermore, the elemental composition did not differ among the sampling sites of the IURG. The rural site was also polluted due to heavy amounts of untreated wastewater of the adjacent Chao Phraya River. Bioaccumulation factors of Ba, Cu, and Mn was higher than 1, suggesting active accumulation of these elements in plant tissue. Our findings proved that the deposition of air pollutants and the resistance to air pollutants in the case of plant leaves were different and that humus materials of the soils had relevant role in bioaccumulation of Al, Ba, and Cu (*Molnár et al. Int. J. Environ. Res. Public Health **2020**, 17, 5165)*.

Study on air pollution tolerance of selected tree species (vi hypothesis)

According to the work plan of project we studied we studied the air pollution of different tree species. *Betula pendula, Fraxinus excelsior, Platanus × acerifolia, Celtis occidentalis, Acer platanoides, Acer saccharinum, Robinia pseudoacacia and Tilis sp.* leaves were collected from an urban park in the city center of Debrecen, Hungary in July 2020. The amount of PM_{10} and PM_5, Air Pollution Tolerance Index (APTI) of tree species, and the trace element concentrations in deposited dust and leaves were analysed.

There were significant differences in the amount of PM_5 and PM_{10} among the studied species. The highest of amount of PM_{10} and PM_5 was found on the leaves of *A. saccharinum* (PM_{10}: 28,0 ± 2,4 µg cm^{-1}, PM_5: 17,6 ± 3,6 µg cm^{-1}) and *B. pendula* (PM_{10}: 28,7 ± 7,5 µg cm^{-1}, PM_5: 11,9 ± 1,9 µg cm^{-1}), while the lowest amount of dust was on the leaves of *F. excelsior* (PM_{10}: 6,8 ± 1,5 µg cm^{-1}, PM_5: 0,4 ± 0,2 µg cm^{-1}). There was also significant difference among species based on tree leaves for ascorbic acid content, the pH of the leaf, total chlorophyll content and the value of APTI. According to the categorisation of Singh et al. (1991) based on the value of APTI, *Betula pendula* (11,2 ± 1,0), *Fraxinus excelsior* (8,8 ± 0,2*), Celtis occidentalis* (10,3 ± 0,7), *Acer platanoides* (10,9 ± 0,4), *Robinia pseudoacacia* (7,2 ± 1,2) *and Tilis sp.* (9,0 ± 0,7) are sensitive, the *Platanus × acerifolia* (17,0 ± 1,0) is moderately tolerant, while the *Acer saccharinum* (23,0 ± 1,4) is tolerant. There was a significant difference among species based on the Al, Ca, Mg, Na, P, Pb, S, Sr and Zn of PM_5, Al, Ba, Mn, Na, P, Pb, Sr and Zn of PM_{10} ; and the Al, Ba, Ca, Cu, Fe, Ni, S, Sr and Zn of leaves (*manuscript preparation*).

Results were published in the following papers

- Molnár, V.É., **Simon, E.,** Tóthmérész, B., Ninsawat, S., Szabó, Sz. (2020). Air pollution induced vegetation stress–the air pollution tolerance index as a quick tool for city health evaluation. *Ecological Indicators 113: 106234.*
- Molnár, V.É., **Simon, E.**, Ninsawat, S., Tóthmérész, B., Szabó, Sz. (2020). Pollution assessment based on element concentration of tree leaves and topsoil in Ayutthaya Province, Thailand. *International Journal of Environmental Research and Public Health* 17: 5165-5179.
- Molnár, V.É., Tőzsér, D., Szabó, Sz., Tóthmérész, B., **Simon, E. (**2020). Use of leaves as bioindicator to assess air pollution based on composite proxy measure (APTI), dust amount and elemental concentration of metals. *Plants-Basel* 9: 1743-1755.
- **Simon, E.**, Molnár, V.É., Tóthmérész, B., Szabó, Sz. (2020). Ecological assessment of particulate material (PM_5 and PM_{10}) in urban habitats. *Atmosphere* 11: 559-567.

Results were published in the following conferences

- Molnár, V.É., Tóthmérész, B., Szabó, Sz., **Simon, E**. Pollution assessment in urban areas using Air Pollution Tolerance Index of tree species. 26th International Conference on Modelling, Monitoring and Management of Air Pollution, 19 - 21, June 2018, Naples, Italy.
- Molnár, V.É., Tóthmérész, B., Szabó, Sz., **Simon, E**. Fafajok pormegkötésének és légszennyezettségi tolerancia indexének meghatározása Debrecenben. 8th Ecotoxicology Conference, 23 November 2018, Budapest (poster)
- **Simon, E**., Molnár, V., Szabó, Sz., Tőzsér, D., Tóthmérész, B. A por, mint légszennyező becslésének tesztelése: porcsapda vs. falevél portartalma. 9th Ecotoxicology Conference, 22 November 2019, Budapest (poster)

- Molnár, V.É., **Simon, E**., Szabó, Zs., Abriha, D., Szabó, Sz. Fajszintű képosztályozás WorldView 2 felvételen. FényTérKéP Conference, 14-15 November, 2019, Tihany (lecture)
- Molnár, V., Szabó, Sz., Tőzsér, D., Tóthmérész, B., **Simon, E**. Légszennyezettség-becslés falevelek biokémiai és elemanalitikai paraméterei alapján. 10th Ecotoxicology Conference, 4 December 2020 (online) (poster)
- **Simon, E.,** Bárány, F.Zs., Molnár, V.É. Falevelek, mint porcsapdák ökotoxikológiai hatása a szárazföldi ökoszisztémára. 10th Ecotoxicology Conference, 4 December 2020 (online) (poster)
- Molnár, V.É., Tőzsér, D., Szabó, Sz., **Simon, E**. Assessment of heavy metal content in leaves of urban trees in Debrecen (Hungary) and Bangkok (Thailand). 3rd World Congress on Environmental Toxicology & Health Safety, May 25-26, 2020 (online) (poster)
- Papp, D., Tőzsér, D., Molnár, V.É., Szabó, Sz., **Simon, E**. Validation of assessment of dust deposition in urban habitats: tree leaves vs dust trap. 3rd World Congress on Environmental Toxicology & Health Safety, May 25-26, 2020 (online) (poster)

Our main scientific new researches

- Our results demonstrated that leaves are useful indicators to assess dust deposition similar to the dust trap. At the same time, our results also indicated that the dust washing is continuous from leaves by rain, and the dust deposition on the surface of leaves is limited because of the capacity of tree leaves.
- We demonstrated that the tolerance of tree species is higher in industrial areas and in cities with high pollution levels than in the control areas. We found a strong positive correlation between the APTI values and the size of cities. The cities showed a separation along the first principal component, which was also correlated with the APTI values and the size of cities. Our results show that the APTI is an efficient tool in air pollution monitoring, and in decision making during urban development and urban greening.
- We demonstrated that monitoring the amount of deposited dust on the surface of urban tree leaves can be an especially useful and effective method for monitoring urban air quality. Both *C. occidentalis* and *T. europaea* are categorized as sensitive based on their average APTI values.
- We demonstrated that *Betula pendula, Fraxinus excelsior, Acer platanoides* and *Robinia pseudoacacia* are also categorized as sensitive, while the *Platanus* × *acerifolia* is moderately tolerant, while the *Acer saccharinum* is tolerant based on their average APTI values.

Difference from financial plan

- The deadline of 2 conferences postponed because of COVID-19 pandemie.
- From the repaid costs we bought additional chemicals and laboratory equipments.

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