TESTING THE BIOREMEDIATION POTENTIAL FOR CERTAIN ATMOSPHERIC POLLUTANTS OF SOME PLANT SPECIES FROM ROMANIA– PRELIMINARY RESULTS

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Abstract

Urban vegetation is widely recognized for its capability to remove / reduce the pollutants in atmospheric air, either by deposition or by stomatal uptake. The main aim of the study was to identify certain species in Romanian flora enable to reduce the concentration of certain gaseous pollutants, and to test their bio-filtration/bioremediation potential related to the underground spaces with auto traffic. Thus, two plant species were tested for their potential in removing a model pollutant (e.g. toluene traces, as a common traffic exhaust pollutant) from the atmospheric air: Hedera helix (Araliaceae) and Chrysopogon gryllus (Poaceae). The selection process of plant species took into consideration the following criteria: well developed foliage, long vegetation period, resistance to hydric stress, shadow tolerance, and aesthetic aspect. The experiments were performed using a small-size airtight greenhouse as an air biofiltration system, having inserted 12 identical pots with selected species (6 with Hedera and 6 with Chrysopogon) and supplied with the model pollutant. A similar set-up in the absence of the model pollutant was considered for comparison purposes. Daily analysis of small air samples from the above mentioned system shows a decrease in pollutant concentration over the course of the test period, without any significant change in plant morphology. The preliminary results highlights the high potential of the investigated (combined) species in improving air quality in the underground spaces with auto traffic, by reducing a model contaminant concentration under experimental conditions. Still, further investigation is needed in order to quantify the individual plant performance towards this pollutant removal as well as their performance under extended gas mixture and the effect of other environmental variables on the efficiency of this process.

Key words: *urban vegetation, plant species, Romanian flora, air pollutants, underground spaces with auto traffic, biofiltration*

1. INTRODUCTION

The role of urban vegetation in bioremediation of air pollutants is widely recognized [1-3]. One of such application is approached in the actual study, as a preamble for developing a botanical biofiltration system for mitigation of air pollutants issued from urban automotive underground spaces (e.g. tunnels, parkings). Such locations are prone to pollutant accumulation from auto traffic, acting thus as a pollutants sink. Among the gaseous pollutants that could be detected in such locations it could be mentioned: nitrogen oxides, sulphur dioxide, carbon monoxide, BTEX (benzene, toluene, ethylbenzene, xylene), 1,3-butadiene, acetaldehyde etc. [4-6]. BTEX are typically approached as relevant VOCs (volatile organic compounds) in studies related to the influence of the auto traffic on urban air quality, with toluene often reported as a dominant pollutant e.g. up to hundreds of ppb can be reached in the contaminated air [7-11]. Total VOC concentration is obviously higher, taking into consideration the presence of a pollutants multitude. Overall, the amplitude of pollutants accumulation depends on the local conditions (traffic intensity, car types, passage dimensions/type, air dynamics, ventilation regime etc.).

Numerous plant species and associated phyllosphere are capable to remove / reduce the pollutants in atmospheric air, either by deposition or by stomatal uptake [2, 12, 13]. Their use represent a more cost

effective and clean alternative to classic adsorption / absorption methods which can produce secondary products and are expensive.

As a consequence, a significant number of studies were focused on identification of most effective plant species in removing atmospheric pollutants and quantifying their bioremediation potential, in both indoor (potted plants) and outdoor (trees) conditions [1, 12-17].

In the current study, species selection process was focused on finding plant species with low emission of biogenic volatile organic compounds and pollen, well developed foliage allowing deposition on leaves surface of particulate matters and a higher rate of absorption of gaseous pollutants through stomata, long vegetation period - species with functional leaves thought the year (evergreen species), as well as the tolerance to stressful environmental conditions and which are widespread within the Romanian habitats. Two species were analyzed:

Hedera helix (English ivy) (Araliaceae) is an evergreen, decumbent (on soil) or climbing shrub, with stems and branches that are fixed on various supports (of any type, from tree trunks, to stone walls), with the help of numerous adventitious roots. The leaves are dimorphic: on vegetative branches they present 3-5 lobes, while on floriferous branches they are more or less ovate [18]. In September – October the plants form small flowers, of yellow-greenish color, grouped in umbels, which will generate dark blue-violet, globose fruits (baccae) with maturation in April – May next year. In native flora of Romania this species frequently occurs from forest-steppe to mountain regions, particularly in forests. Also, is widely cultivated as ornamental species. It is a species with Atlantic – Mediterranean origin, preferring shady habitats, with temperate climate and moderately moist soils. In optimal condition it can reach up to 30 m in length [18]. Except the most acid, *Hedera helix* tolerates all other soil types [19]. It can tolerate certain salinity levels [20] and also the very dry soils [19]. It is also well adapted to indoor cultivation and is recognized for its capacity of removing certain VOCs in indoor conditions, as volatile formaldehyde [21, 22]. Outdoors, it is a traditionally used plant for green walls and facades because of its capacity to cover huge window-free walls [23]. This species requires little maintenance, while trapping the airborne particulates in the dense foliage and regulating (to some extent) the building surface temperatures [23]. *Hedera helix* was tested and found effective in removal of other VOCs such as benzene or toluene [12, 22, 24].

Chrysopogon gryllus (Poaceae) is a monocotyledonous, geophyte, perennial bunchgrass, with a thick rhizome, and a stem with height of 50-150 cm. The leaves are 2-5 mm in width, pubescent and the spikelets (with 3 flowers) are grouped in large panicles (10-20 cm in length). In native flora of Romania this species frequently occurs in steppe and forest-steppe zones, in dry grasslands, clearings of shrub or forest communities or sandy areas [18]. It is a species with sub-Mediterranean origin, preferring dry and oligotrophic soils, and a warm climate. We selected for our study the species *Chrysopogon gryllus*, native in Romanian flora taking into consideration the capacity of other species in *Chrysopogon* genus (e.g. *Chrysopogon zyzanioides*) to remove some BTEX compounds – benzene, toluene, xylene [25].

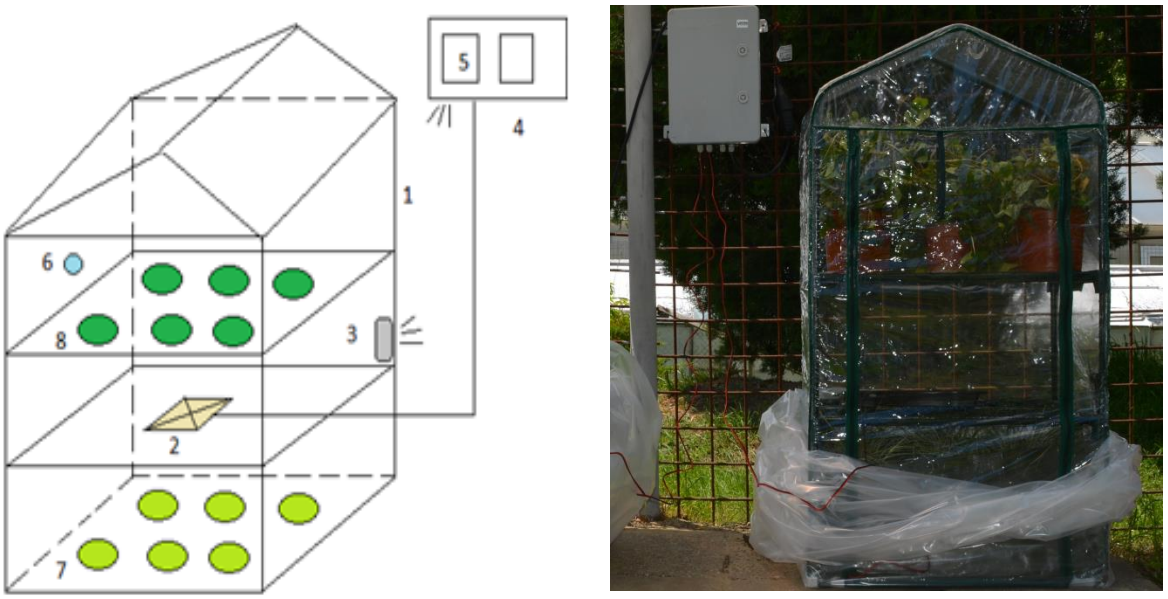
The main aim of the study was to identify certain species in Romanian flora enable to reduce the concentration of certain gaseous pollutants, and to test their bio-filtration/bioremediation potential related to the underground spaces with auto traffic. Plants from the spontaneous flora i.e. *Hedera helix* and *Chrysopogon gryllus* from national resources are going for the first time to be assessed in a such context, using a model aromatic hydrocarbon pollutant (i.e. from the BTEX class), pointing out the pollutant removal capacity of these plants.

2. MATERIALS AND METHODS

2.1. Experimental set-up

The plants (*H. helix*, *C. gryllus*) have been collected from their natural habitat (forests and dry grasslands around the city of Iasi), being acclimatized for about one week to the outdoor conditions at the Botanical Garden of Iasi, where the study was carried out. Then, 12 identical pots with those selected species (6 pots with *H. helix* and 6 pots with *C. gryllus*) have been inserted in a small-size

airtight greenhouse (total volume of 0.4 m^3) to form a biofiltration system (Fig. 1), which was further supplied with the model pollutant (e.g. toluene) to reach the desired initial concentration. A ventilation fan unit was used to assure a uniform gas distribution inside the system. A similar set-up in the absence of the model pollutant was considered for comparison purposes. A multi-channel wireless device (Auriol radio-controlled weather station, Germany) was used for the monitoring of temperature (t) and relative humidity (RH) inside/outside both test chambers.



a b

Fig. 1. Experimental set-up of the botanical biofiltration system:
a) schematic diagram; b) photo capture

1 - airtight greenhouse; 2 – ventilation fan unit; 3 – internal unit for temperature and RH reading; 4 – control panel; 5 – external unit for temperature and RH reading (wireless coupled to 3); 6 – port for gas supply / gas sampling; 7 – pots of plants (*C. gryllus*); 8 – pots of plants (*H. helix*).

The number of plants is established considering that a relatively high plant density might be required for adequate pollutant removal performance, but also for better observation of any plant emission in the reference system. For example, a theoretical plant density of 5 plants/m^2 could assure an enhanced air treatment performance, which might be not practically reasonable for some indoor applications [26]; however, high plant density could become more suitable for semi-outdoor applications such as tunnels and parkings with auto traffic.

2.2. Experimental methodology

In order to figure out the limits and the capability of the investigated plants to remove toluene from the system, several trials using same plants have been successively carried out at different initial toluene concentrations (e.g. 45 ppm – trial 1; 95 ppm – trial 2; 143 ppm – trial 3) for about 3 days each one. These concentrations are also close to or above the national maximum admissible values for the occupational exposure e.g. 50 ppm for 8 hours or 100 ppm for 15 minutes [27]. Prior each experiment, plants have been exposed for one day to the presence of small toluene concentration (e.g. below 10 ppm), allowing their acclimatization and minimizing the potential adverse effect that could be associated with the pollutant load. Some morphological characteristics such as leaf area were estimated, as a main pollutant-plant contact surface. After each trial, the plants were visually observed for healthy appearance and prepared (e.g. watered) before returning in the test chamber for the next trial.

For each trial, small air samples from the test chambers have been daily collected in Teflon bags at different time intervals and analyzed in the same day by using a Micro GC Fusion Gas Analyzer (Inficon, USA), allowing gas monitoring in terms of not only model pollutant (e.g. toluene), but also looking for other gases as well (e.g. oxygen, other VOC peaks).

3. RESULTS

A decrease in the toluene peaks was observed over the course of the testing period for all related trials (an example is provided in Fig. 2). When high initial pollutant concentrations were involved (trials 2 and 3), total toluene uptake was completed within 48h hours, from which most of the toluene was removed during the first 24 hours (Fig. 3). No further desorption phenomenon was observed up to the end of the trial interval (72h). When plants have been exposed to small initial pollutant concentrations (e.g. below 45 ppm, as for trial 1 and the acclimatization stage) a very fast pollutant uptake occurred (e.g. within the first few hours of exposure).

Based on the obtained chromatograms, no any VOC emission was observed for the plants from the reference biosystem (subject to the GC detection limits, e.g. below 1 ppm). Moreover, no change in plant morphology was observed as result to the pollutant loads exposure. Longer tests should be performed, while considering minimizing other plant stress conditions associated with the sealed environment. No significant oxygen depletion that could affect the plant performance was observed on the short term, as the oxygen concentration fluctuated in a quite constant range (19.4÷20.9 %) for both systems in the actual trials.

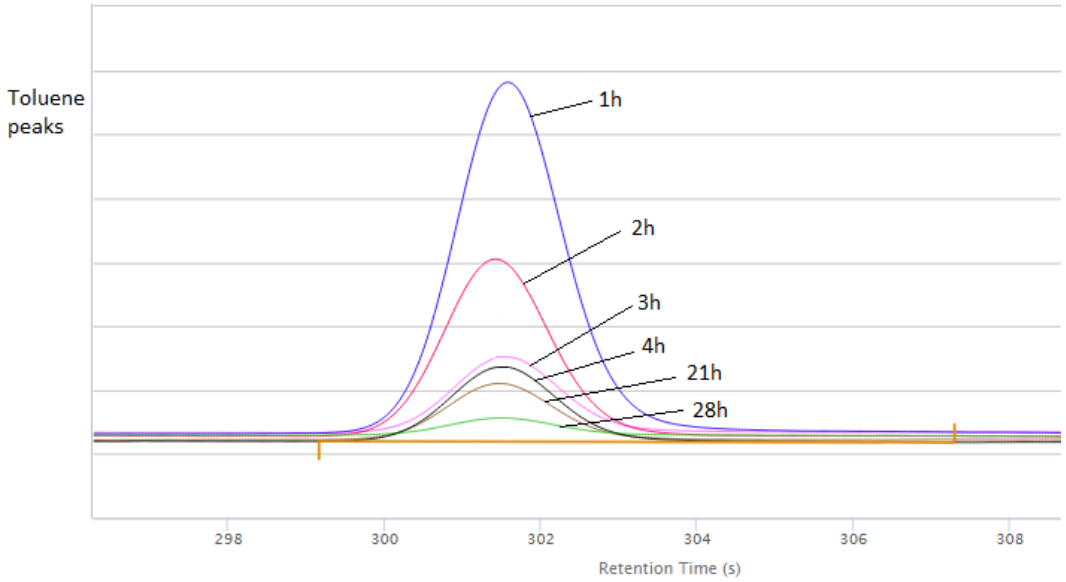


Fig. 2. Example of toluene peaks at different sampling times

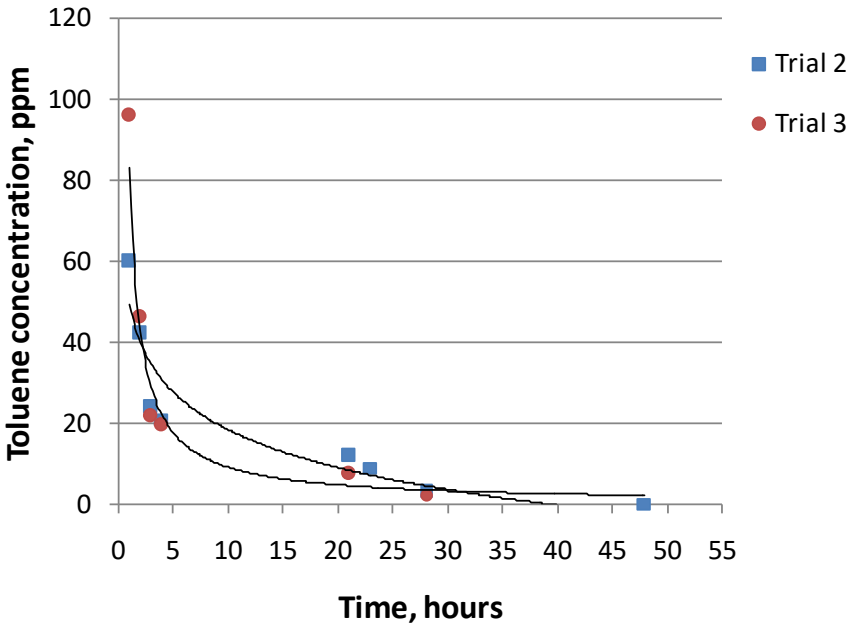


Fig. 3. Time dependence of toluene concentration (trial 2: c_i = 95 ppm; trial 3: c_i=143 ppm; trial 1: c_i = 45 ppm - not shown (fast pollutant removal))

4. DISCUSSION

The biofiltration performance observed in the actual study could be related to the toluene fixing by the aerial part of the plant (e.g. leaves, stems and their associated phyllosphere and endosphere) for the biomass development, as one of the main toluene removal pathways on the short term (as in the actual study), subject to sorption-related process. The plant soil was also exposed to the pollutant, thus some toluene biodegradation by rhizosphere microorganisms could be also expected to occur, especially on the longer term. Such mechanisms are detailed in several studies [28-31]. Taking into consideration that the toluene is not involved in the respiration process, any additional CO_2 production (in comparison with the normal plant respiration) could be related to such microbiological metabolism.

Comparable results are described in other studies related to VOC removal by plants. For example, above 70% of 20 ppm toluene was removed by 0.0013 m^2 leaf area-based pot in about 72 h in the study of Sriprapat et al. [13], which was carried out with different individual indoor plants. In their study, the soil was covered by an aluminum foil to allow the determination of only aerial plant contribution to the pollutant removal performance. Also, the maximum removal (e.g. above 90%) of other VOCs such as benzene has been achieved in about 30 h by a pot located in a test chamber supplied with an initial benzene concentration of 5 ppm, where different individual indoor plants were also tested as well [32]. A linear decrease trend was observed in their case for all the tested plants. Between 3-6 days were also reported for the complete removal of benzene by several indoor plants (i.e. one potted plant per 0.2 m^3 chamber), where initial benzene concentration ranged between 25-50 ppm [33]. Moreover, *H. helix* was the most performance plant in toluene removal in the study of Yoo et al. [34].

The higher pollutant removal rate in the actual study in comparison with the above exemplified studies could be explained taking into consideration the higher plant number (i.e. higher foliar area). Particularly, the pollutant concentration decrease followed a power and a logarithmic trend for the trials 3 and 2 (Fig. 3), respectively, which suggests the existence of two kinetic stages (faster and slower). Overall, the actual results confirm that the mixture of two plant species from national resources investigated in this study (i.e. *H. helix* and *C. gryllus*) can adapt to the stress pollution

conditions such as those associated with the auto traffic and can achieve a high pollutant removal efficiency.

Therefore, this study shows the suitability of using the investigated plants (*Hedera helix* and *Chrysopogon gryllus*) in such air treatment applications. Although the mixture of these plants exhibited promising results, the contribution of each plant type to the overall process performance under different operating conditions could be further addressed, along with other parameters monitoring (e.g. CO_2 monitoring as an indicator of the biological process). In practice, complex gas mixtures are associated with the urban underground auto traffic, thus plants screening in the presence of multiple pollutants can be considered as well during the biotechnology development. For instance, xylene removal by the same plants, alone or in the presence of toluene, led to promising results in some additional trials (e.g. Fig. 4). Also, toluene and benzene have been simultaneously removed by *H. helix* in the study of Yoo et al. [34], while exhibiting double performance in the removal of toluene than benzene. Particularly, a theoretical concept ("Chimney stack phytosystem") for treating air of such environments, which is emphasized by Irga et al. [35], could be considered to reduce energy loads while improving air quality and reducing emissions from the source.

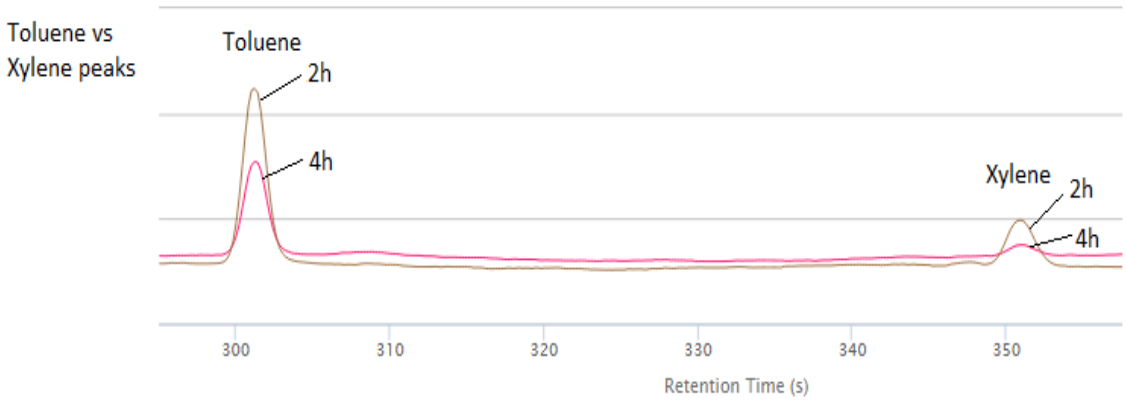


Fig. 4. Example of toluene and xylene peaks at different sampling times (for a volumic ratio of 2/3 toluene and 1/3 xylene)

5. CONCLUSIONS

The performance of a botanical biofiltration system containing two plant types from the Romanian flora (*Hedera helix* and *Chrysopogon gryllus*) was screened towards toluene removal from air. A total removal of this pollutant was recorded after 48 h or less, depending on the initial concentration. Almost similar performances were obtained using air contaminated with xylene or xylene-toluene mixture as well. These results show the opportunity for involving these plants in the development of the botanical biofiltration systems for the air treatment from the urban underground auto traffic. In the same time, this study shows for the first time the opportunity of using plants from Romanian flora for such air treatment applications.

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