CARBON DIOXIDE REDUCTION POTENTIAL OF SOME PLANTS INVOLVED IN THE REMOVAL OF AIR POLLUTANT MIXTURES BY BIOFILTRATION

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Abstract

The beneficial role of plants in earth's atmosphere revitalization is a driving force for developing specialized plant-based air treatment biosystems. In this study, the biofiltration performance of some plants (Hedera helix, Dypsis lutescens, Chlorophytum comosum) is assessed, by their exposure to a gas stream containing either sole atmospheric carbon dioxide (plant mixture and individual plants) or both organic and inorganic compounds (toluene, xylene, carbon dioxide, nitrogen dioxide) (plant mixture). The influence of the biological matrix components (compost-based substrate, plant), plant density and the light conditions is observed, allowing pointing out some key process aspects. Except carbon dioxide, all other gaseous contaminants were completely removed under the studied conditions. The biodegradation of volatile organic compounds is an in-situ source of carbon dioxide in botanical biofilters, but this issue can be overcome by stimulating the photosynthesis process through appropriate illumination. For instance, about 60% carbon dioxide removal was reached, with the possibility to extend this performance via the specific system conditions. These results show that such plant-based designs can be considered as an emergent and affordable environmental-friendly option for simultaneously removal of carbon dioxide and other gaseous contaminants in the same unit, solving issues related to indoor or outdoor air pollution. Particularly, implementation of such biosystem for diminishing the gaseous pollutants generated from the auto traffic in urban automotive underground spaces, could significantly contribute to the efforts of reducing the environmental impact associated with auto emissions in urban places.

Keywords: *biofiltration, plants, gaseous pollutants, auto traffic, air treatment*

1. INTRODUCTION

Carbon dioxide, oxides of nitrogen, and aromatic volatile compounds resulted from combustion of fossil fuels are the most significant components of atmosphere pollution both in urban automotive underground spaces as well as in outdoor spaces, with negative effect on both human health and environment. Among the numerous approaches developed to improve air quality, phytoremediation is an affordable and environmental-friendly option. Previous studies have shown that VOC removal depends on plant species [1, 2] while selection of the plant species influence the VOC removal efficiency [3]. Thus, in this study, three plant species were tested for their ability to act as a biofilter as well as for their efficiency in VOC removal.

Dypsis lutescens (H.Wendl.) Beentje et J. Dransf. (*Arecaceae*) - dioecious palm species, which in the natural environment forms bushes with 4-20 stems, 1-7 m high and 5-12 cm in diameter. The leaves are feathery compound, 5-11 on the stem, are spiral and strongly arched, 40-60 cm long, with 45-60 leaflets on each side of the spine. The flowers are yellow, on type 3, arranged in inflorescences. The fruit has a yellow color and an ellipsoidal shape, with a long fibrous endocarp and seeds with a

homogeneous endosperm [4]. It is an endemic species in Madagascar, spread on the east coast of the island (white sand dunes on the coast of the Indian Ocean) and sporadically along rivers in the lowlands, on swampy areas [5]. It is a very popular palm in culture; it is cultivated as an ornamental species in parks and gardens in tropical and subtropical regions, or as a houseplant in temperate areas. Prefers well-drained, aerated, neutral soils with moderate fertility. Dypsis lutescens is a species known for its indoor air purifying properties. Thus, Bhargava et al. (2021) [6] reported efficiencies of over 95% in reducing the amounts of VOCs, CO and CO_2 by using the areca palm (in pots), considering the species an efficient, cost-effective and sustainable solution for improving indoor air quality.

Chlorophytum comosum (Thunb.) Jacques (*Asparagaceae*) - the spider plant, is a perennial herbaceous plant, with tuberous roots and permanent, linear leaves, up to 40-50 cm in length. The stems are flexible, up to 1 m in length, and the flowers are white, solitary or arranged in inflorescences (racemes). The fruit is a capsule. It shows rapid growth. It is a plant originating in the tropical areas of Africa, and in Romania it is a very popular indoor species, which easily adapts to various growing conditions. It prefers semi-shaded spaces, but tolerates both direct sunlight and shade. It grows well on well-drained substrates with neutral or slightly alkaline pH [7]. The species has been extensively studied for its ability to improve indoor air quality. Thus, it was highlighted its effectiveness in removing formaldehyde [3,8], benzene [9, 10], carbon monoxide, xylene [11] and particulate matter of any category [12]. Superior efficiencies in the removal of VOCs (complementary to low CO2 emissions) have been reported by [8] by combining two species: *Clorophytum comosum* and *Sansevieria trifasciata*. It has also been found that *Clorophytum comosum* is also effective in removing ethylbenzene, in this case the purification rate does not depend on the number of stomata but on the chemical composition of the wax on the surface of the leaf cuticle [13].

Hedera helix (*Araliaceae*) - English ivy is an evergreen shrub of Atlantic-Mediterranean origin, either decumbent on soil, or climbing using adventitious roots on different support types as trees, fences, house facades, walls, etc. It presents dimorphic leaves, with 3-5 lobes on vegetative branches and ovate on the flowering ones [14]. The flowers are small, yellow-green and occurs in early autumn. The fruits are globular, dark blue-purple berries. It is a widespread species in Romania, preferring the shady habitats and moderately moist soils from forests and a temperate climate. It is widely cultivated both indoors and outdoors as a decorative plant. A significant number of studies highlighted Hedera helix as a very effective species in removing a wide spectrum of VOCs, such as formaldehyde, benzene or toluene [15-19].

The aim of current study was to assess the biofiltration performance of above-mentioned plant species in different experimental conditions (single species - mixture of species, sole pollutant - multiple organic and inorganic compounds) and to evaluate the bioabsorption/biodegradation rate in different light conditions.

2. MATERIALS AND METHODS

2.1. Experimental set-up

The experiments have been carried out in biofilters (BFs) consisting in plexiglass cylindrical columns equipped with the biopacking bed (plants and their growing compost-based substrate or sole compost granules) prepared for the gaseous contaminants capture from the processed air. A substrate/bed volume of about 2.2 L was involved in each BF. The contaminated air was continuously fed in the column via a port located at the bottom of the column, while the treated air was evacuated at the top. BFs were occasionally irrigated by using distilled water. The gaseous flux was transported via a pumping system, while irrigation was manually performed. BFs were operated under natural and artificial illumination conditions, respectively. In the last case, two oppositely positioned LED lamps (white light) were added outside of the column, along with an aluminum folium for a uniform light distribution. The diagram of the biofilter setup is shown in the following Figure (the plant-based case).

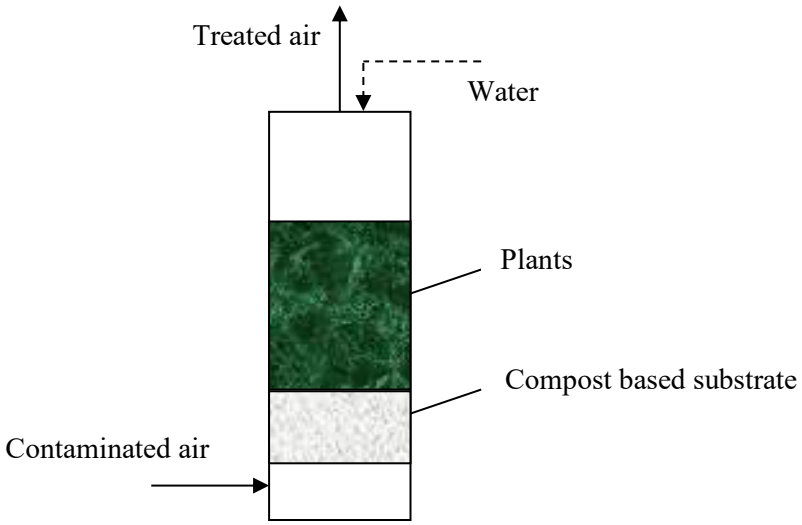


Fig. 1. Botanical biofilter set-up

2.2. Experimental methodology

The following plant types have been investigated for the assessment of their biofiltration performance of various contaminants from the gas streams: *Hedera helix*, *Dypsis lutescens* and *Chlorophytum comosum*. Commercial plants have been considered for this purpose, being transferred from their original soil in a compost-based substrate (a commercial vegetal compost rich in active humus) prior starting the experiments. Moreover, a plant type from the Romanian flora (*H. helix* (Ro)) was involved in some tests, for comparison purposes. Also, the sole compost (prepared as granules of 1-2 cm) was investigated under similar conditions, in order to determine its role in the contaminant removal. Three plants (as mixture or individual) were involved in each BF. In order to test the influence of the plant density on the biofilter performance, the number of plants was doubled (i.e., 6 plants, consisting in two plants of each plant type).

The investigation of the biofiltration performance of the BFs containing the packing beds prepared as above was performed by continuously feeding the BFs with the gas stream to be treated at a flowrate of 0.5 L/min. The gas stream contained either sole atmospheric carbon dioxide (plant mixture and individual plants) or both organic and inorganic compounds (toluene, xylene, carbon dioxide, nitrogen dioxide) (plant mixture) at the following contaminant concentrations: 350-450 ppm CO_2, 10-35 ppm toluene, 7-23 ppm xylene, 5-15 ppm nitrogen dioxide. The gas mixture was prepared by mixing the carrier air with toluene and xylene - rich air generated from individual gas washing bottles containing the respective organic solvents and with nitrogen dioxide-rich air from a pre-prepared Tedlar bag of about 200 L capacity. Inlet and outlet gas samples were analyzed by a GC Fusion Gas Analyzer (Inficon, USA), which was correlated with a pre-calibrated FTIR gas analyzer (Gasmet GT5000 Terra, Finland), allowing to determine the biofiltration performance according to the equation **(1)**. A digital light meter (Extech LT300, USA) was used for the measurement of the light intensity.

$$RE, \% = (c_{IN} - c_{OUT}) \cdot 100 / c_{IN} \quad \textbf{(1)}$$

where:

RE = removal efficiency; c_{IN} – inlet contaminant concentration; c_{OUT} = outlet contaminant concentration.

An acclimatization time of several days was observed in the case of using the multiple gases, after which the system response to the change in the system conditions was quite fast and steady. Biofiltration performance under natural lighting conditions (day/night regime) was maximum for all

involved contaminants, except CO_2, which exhibited the highest removal at the maximum observed light intensity during the day (30 kLux). Therefore, this light intensity was also considered for the experiments carried out under artificial lighting conditions. In this last case, a continus illumination was applied in order to maintain the photosynthesis process involved in CO_2 removal.

3. RESULTS

The obtained results are summarized in Figs. 2-4, where the influence of the biological matrix components (compost-based substrate, plant), plant density and the light conditions is observed.

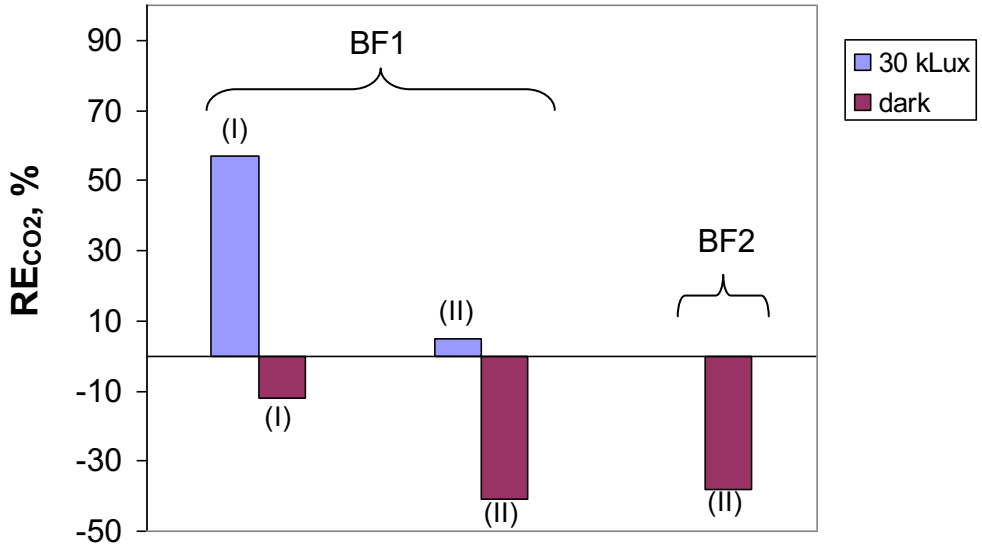


Fig. 2. Influence of the natural light conditions and air composition on the carbon dioxide removal from: (I) ambiental air (350±50 ppm CO_2); (II*) contaminated air (350-450 ppm CO_2, 10-35 ppm toluene, 7-23 ppm xylene, 5-15 ppm NO_2). BF1 – mixture of three plants (*H. helix*, *D. lutescens*, *C. comosum*); BF2 - compost only; *all contaminants, except CO_2 are completely removed

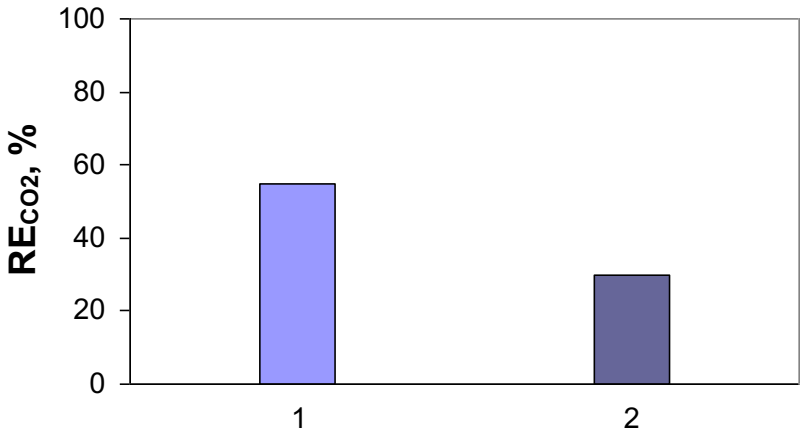


Fig. 3. Influence of the plant density on CO_2 removal from ambiental air, at 30 kLux (artificial light), by the plant mixture: 1 - three plants; 2 - six plants

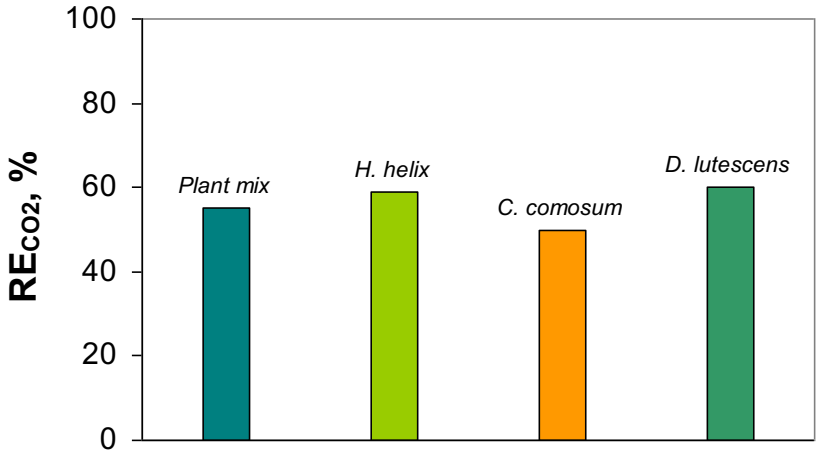


Fig. 4. CO_2 removal performance during the treatment of the ambiental air by the plant mixture versus the individual plants (three plants involved in each BF), at 30 kLux (artificial light).

4. DISCUSSION

As earlier mentioned, except carbon dioxide, all other gaseous contaminants were completely removed under the studied conditions. The negative values observed for RE_{CO2} in Fig. 2 are due to the CO_2 production by plants in the absence of light (e.g. at night). Moreover, the biodegradation of volatile organic compounds such as toluene and xylene is an in-situ source of carbon dioxide in biofilters and can explain the pronounced negative RE_{CO2} values during the treatment of VOC-rich air in the case of both types of biofilters (plant-based (BF1) or compost-based (BF2)). This drawback can be particularly overcome in the case of BF1 by stimulating the photosynthesis process through appropriate illumination.

As can be seen in Fig. 2, RE_{CO2} become positive in the presence of light, with about 60% carbon dioxide removal from ambiental air being reached in the presence of light (30 kLux), with the possibility to still extend this performance via the specific system conditions (results not shown). The lower RE_{CO2} in the case of treating air contaminated with multiple gases is due to the simultaneous CO_2 removal through photosynthesis and CO_2 production during VOC degradation (Fig. 2).

The decrease in RE_{CO2} with the increase of the plant density (Fig. 3) can be due to the shading effect induced by the dense plants. A higher plant density can limit the access of the light to the plants, affecting their photosynthesis efficiency. On the other hands, excessive increasing of the light intensity or of the lighting sources may have an adverse effect on the plant development (dryness, photoinhibition, [20]), thus careful selection of the lighting conditions should be envisaged.

Fig. 4 shows the variation of the RE_{CO2} en function of the different plant types investigated in this study, either as mixture or as individual plants. As it can be seen, RE_{CO2} ranged around 60% for all cases, suggesting no competitive / inhibitory effects between plants when used in the mixed configuration. Thus, from an aesthetical point of view, a mix of plants can be used for air biofiltration, but individual plants can be also considered for a better process control and depending on the application. For example, implementation of such biosystem for diminishing the gaseous pollutants generated from the auto traffic in urban automotive underground spaces, could significantly contribute to the efforts of reducing the environmental impact associated with auto emissions in urban places. In a previous related study carried out under static conditions, *H. helix* (Ro) exhibited promising results in terms of toluene and xylene removal, which are some of the pollutants issued from the auto traffic. Moreover, the presence of NO_2 along with them in the actual study didn't affect the performance of *H. helix* in such VOC removal. The actual study provide more information in terms of its CO_2 removal

capacity under dynamic conditions. For instance, the RE_{CO2} was slightly higher in the case of *H. helix* and *D. lutescens*, in comparison with *C. comosum* and the plant mixture.

5. CONCLUSIONS

This study addresses some key process aspects that could be considered when using plants in biofilters for multi-pollutant removal from gaseous streams, including both organic and inorganic gaseous compounds. The obtained results indicates that all the investigated plants (*Hedera helix*, *Dypsis lutescens*, *Chlorophytum comosum*, considered either as plant mixture or as individual plant) can efficiently remove the model pollutants such as toluene, xylene and nitrogen dioxide from the gaseous streams, along with some of the carbon dioxide, subject to the light conditions for this last one. Although CO_2 removal is stimulated by the enhanced light intensity, this performance is decreased in the presence of the organic compounds due the simultaneous CO_2 production from their biodegradation. For instance, about 60% CO_2 removal from ambiental air was reached at 30 kLux, at a low plant density. Operating the biosystem at a higher plant density should be avoided due to the shading effect and the higher light intensity may be associated with photoinhibition as well. CO_2 removal performance was slightly higher in the case of *H. helix* and *D. lutescens*, in comparison with *C. comosum* and the plant mixture. Overall, these results show that such plant-based designs can be considered as an emergent and affordable environmental-friendly option for simultaneously removal of carbon dioxide and other gaseous contaminants in the same unit, solving issues related to air pollution. Particularly, plants from national resources such as *H. helix* could be considered in this regard.

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