PRELIMINARY ASSESSMENT OF AIR PURIFICATION BY AERIAL PLANT BASED BIOFILTER

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Abstract

The air purification performance of an aerial plant based biofilter was investigated in this study, as an alternative option to the more common botanical biofilters that are mainly based on terrestrial plants. The experiments have been carried out by using a mixture of different plant species from Tillandsia genus for carbon dioxide (the model contaminant) removal from atmospheric air, under different operating conditions (air flowrate, plant density, lighting conditions). The CO_2 removal efficiency was light dependent and significantly influenced by the air flowrate. Additionally, individual plant species (T. xerographica) was also assessed at a higher gas-plant contact time, reaching about 80% CO_2 removal efficiency. Further exploring this CO_2 capture potential, along with the possibility to remove other contaminants as well, can be envisaged in future studies for developing such biosystems for special applications (e.g., mitigation of gaseous pollutants from auto traffic etc.). Particularly, such aerial plant doesn't require a soil substrate for growing, reducing the biofilter maintenance and allowing a better process control, which may make it an interesting candidate for space applications, as well.

Key words: *aerial plants, Tillandsia sp., biofiltration, auto traffic, air revitalization*

1. INTRODUCTION

The air purification performance of an aerial plant based biofilter was investigated in this study, as an alternative option to the more common botanical biofilters that are mainly based on terrestrial plants. Aerial plants are epiphytic species widely used as ornamental plants but also for biomonitoring and bioremediation of air pollution [1-4]. They are widespread in tropical and subtropical regions and comprise (among others) numerous orchids and bromeliads, including tillandsias.

Including almost 700 species, *Tillandsia* is the most diverse genus in *Bromeliaceae* [5, 6], with an areal overlapping the Neotropical biogeographical realm [7]. All are epiphyte species, with a Crassulacean acid metabolism (CAM) allowing them to increase the efficiency of the water use and to live especially in arid environments. The main particularity of *Tillandsia* species is the presence, on the leaf epidermis, of an increased number of trichomes specialized in absorption of water and nutrients directly from atmosphere [2, 7, 8], facilitating their development from deserts to rainforests [9]. Because of their high capacity to retain nutrients and moisture, they were also tested for their capability to act as natural biofilters in order to remove some atmospheric pollutants. On this line, some species as *Tillandsia usneoides* and *Tillandsia stricta* have been found to be very effective in removing the formaldehyde in indoor spaces [2]. In addition, there was highlighted the capability of *Tillandsia usneoides* (Spanish moss) to adsorb the Hg through scales stems and leaves [1], to remove different particulate matter types [4], organic pollutants [3] or numerous heavy metals [10, 11].

In the current study, a mixture of 11 taxa within *Tillandsia* genus were investigated, with a focus on *T. xerographica*, an aerial plant native in Mexico and El Salvador, Guatemala and Honduras, where it grows on trees but also on rocks. It is an acaulescent plant, of 20-60 cm in height, with gray-silver green leaves, arranged in rosettes. The flowers are tube-shaped, pale lilac, arranged in inflorescence up to 30 cm in length, with imbricated floral bracts, green or yellowish red. In natural habitats it presents a very slow growth - it takes between 12 to 18 years to produce flowers. Vegetative reproduction is made by sprouts developed from buds in the axil of some basal leaves [12]. The species threatened with extinction because it is collected from the wild in large numbers and included in CITES convention on international trade (https://cites.org) [13]. To our knowledge, this particular species was not yet tested for its bioaccumulation capacity or removal of some VOCs from atmosphere. One of such aerial plants' advantage is their use as it is, without any soil amendment and a minimum nutrients/water requirement.

On the other hands, VOC biodegradation in biofilters occurs with the formation of carbon dioxide, which should be also avoided due to its greenhouse effect and contribution to the global warming potential associated with the climate change. Moreover, CO_2 is a typical compound issued from fuel combustion in different sectors (transportation, electric power generation etc.) and its concentration in atmospheric air is gradually increasing, rising environmental concerns. Therefore, addressing CO_2 removal could be considered as a first attempt in tailoring botanical biofilters for decontamination of the gaseous streams contaminated by VOCs and CO_2. In other words, CO_2 removal by plants can be stimulated by carrying out the biofiltration process under illumination conditions, via the photosynthesis mediated by light. These conditions didn't affect the simultaneous removal of the other organic or inorganic treated pollutants (xylene, toluene, nitrogen dioxide) in the case of the terrestrial plants [14].

The current study was focused on the following questions: i) are the plants within *Tillandsia sp.* efficient in removal of carbon dioxide from atmospheric air? ii) is the removal rate better using a particular species (e.g. *T. Xerographica*) or a mixture of species? and iii) what is the effect of the operating conditions on the carbon dioxide removal efficiency? The experiments have been carried out under dynamic regime, allowing to point out the favorable conditions for CO_2 removal, that could be further used for moving on VOCs and other contaminants removal as well.

2. MATERIALS AND METHODS

2.1. Experimental set-up

Fig. 1 shows the experimental set-up of the biofilter investigated for CO_2 removal from ambiental air. The biofilter was made from a plexiglass column containing the *Tillandsia* sp, which was continuously fed with ambiental air in order to investigate its atmospheric CO_2 removal efficiency under dynamic regime. Irrigation by distilled water was occasionally performed. The experiments have been performed with (Fig. 1): a mixture of *Tillandsia* species (BF1); sole *T. Xerographica* (BF2). The biofilters were illuminated by using two LED lamps (oppositely located outside of the column) and surrounded by an aluminum folium for enhanced light distribution.

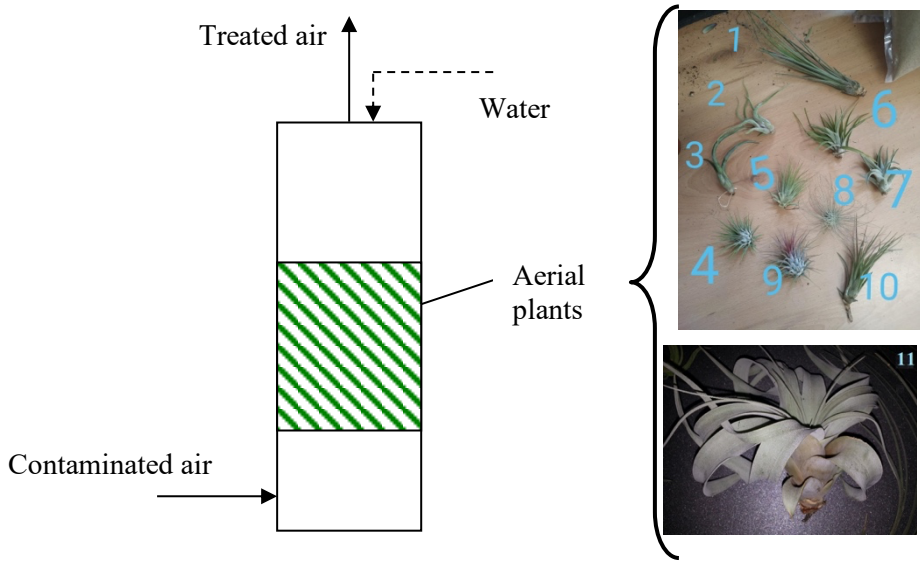


Fig. 1. Biofilter set-up

1. *Tillandsia Jucea;* 2. *T. Caput Medusae;* 3. *T. bulbosa;* 4. *T. Scapose;* 5. *T. Ionantha Green;* 6. *T. Abdita;* 7. *T. Harrisii;* 8. *T. Argentea;* 9. *T. Ionantha Red;* 10. *T. Tricolor;* 11. *Tillandsia Xerographica*

2.2. Experimental methodology

The botanical biofilters (BF1, BF2) were continuously fed using an air pump with ambiental air containing atmospheric CO_2 for about two months. During this time, the biofilter was manually irrigated with distilled water upon request (e.g. once a week). The air to be treated was fed at the bottom of the column, allowing the gas to ascendently pass through the plants for the biological CO_2 capture. The treated air was then evacuated at the top of the column.

The influence of the following conditions on the botanical biofiltration performance was investigated: plant density, light intensity and gas flowrate. The plant density was varied by varying the number of the plants in each biofilter (i.e., from 11 to 22 for BF1, and from 3 to 6 for BF2, respectively). The light intensity was ranged from dark (0 kLux) to 30 kLux, switching from an initial night/day regime to a continuous lighting regime at different distances between the light source and the biofilter. The air flowrate was ranged between 0.015-1 L/min, being controlled by a gas flowmeter. A digital light meter (Extech LT300, USA) was used for the measurement of the light intensity.

The CO_2 removal efficiency was determined according to eq. (1), on the basis of the CO_2 concentration before and after the biofilter, which was analyzed by a GC Fusion Gas Analyzer (Inficon, USA).

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

where:

RE = removal efficiency;

$c_{inlet,\ outlet}$ = inlet/outlet contaminant concentration.

3. RESULTS

Figs. 2-5 show the system response to the change in the gas flowrate, plant density and light intensity, in terms of CO_2 removal efficiency (RE_{CO2}, %). Also, Fig. 6 provides additional information for evaluating the gas composition transition during the botanical biofiltration, in terms of not only CO_2, but also oxygen and water vapour upon case.

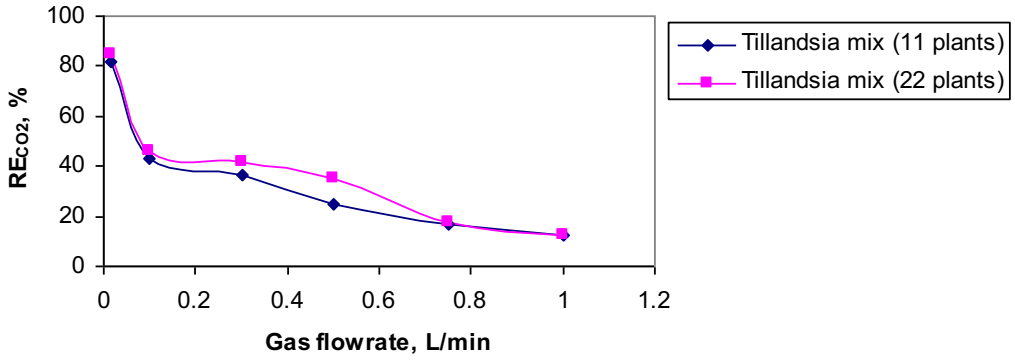


Fig. 2. Variation of CO_2 removal performance by BF1 at 30 kLux as a function of gas flowrates and plant densities

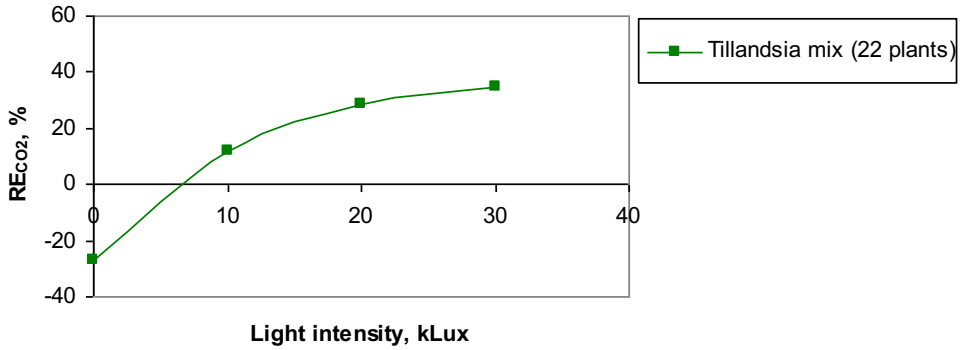


Fig. 3. Variation of CO_2 removal performance by BF1 at 0.5 L/min as a function of light intensity

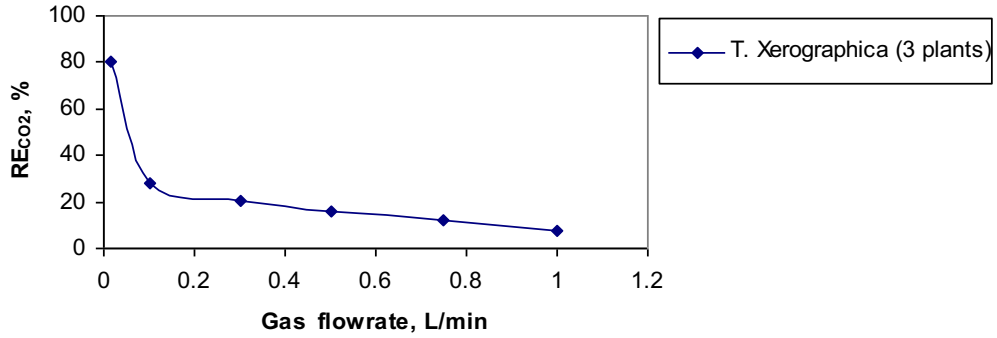


Fig. 4. Variation of CO_2 removal performance by BF2 at 20 kLux as a function of gas flowrate

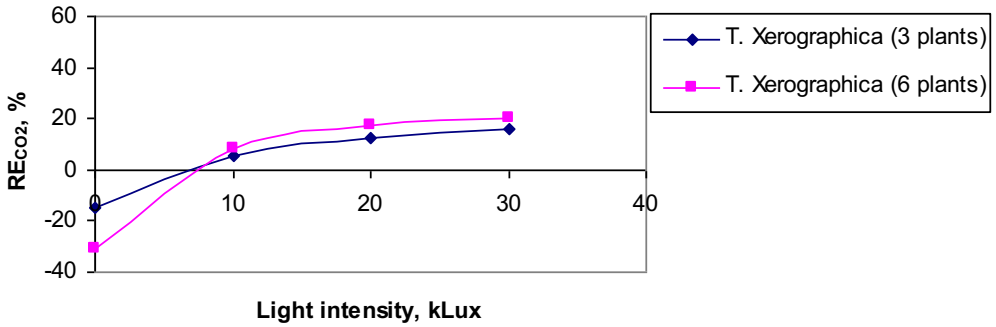
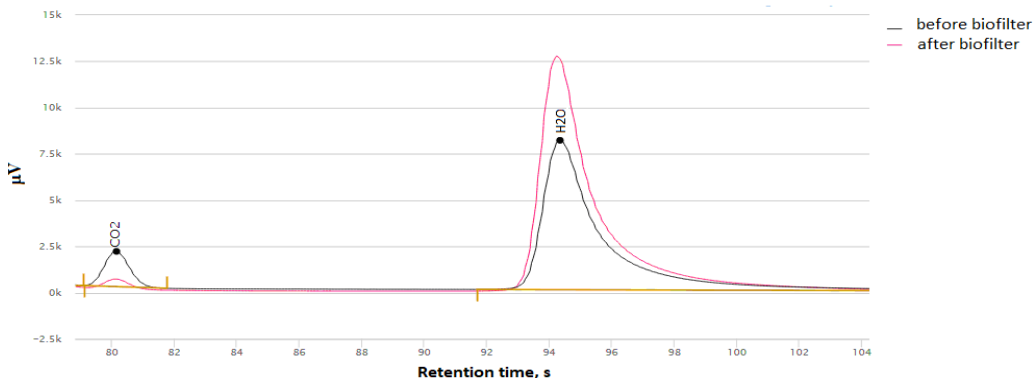
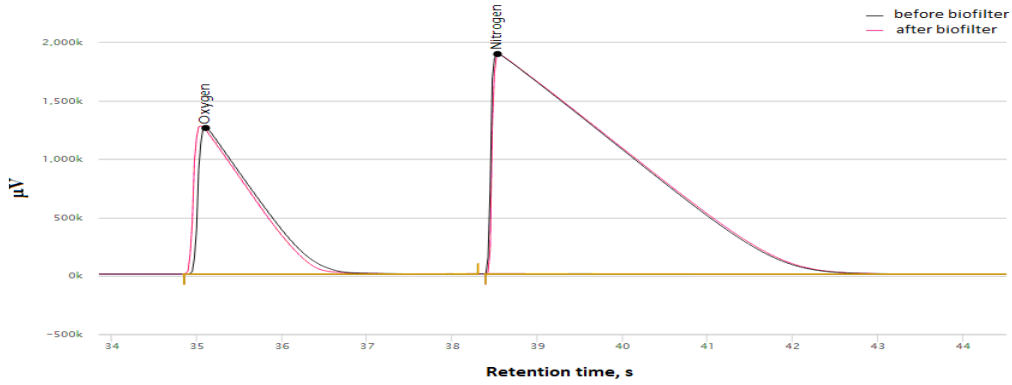


Fig. 5. Variation of CO_2 removal performance by BF2 at 0.5 L/min as a function of light intensity and plant density



(a)



(b)

Fig. 6. CO_2 biofiltration by BF2 (T. Xerographica - 3 plants), at 0.015 L/min: evolution of CO_2 (a) and O_2 (b) as result of plant intervention (20 klux)

4. DISCUSSION

As earlier mentioned, one of the main particularities of *Tillandsia* sp. refers to their Crassulacean acid metabolism (CAM), e.g., involving CO_2 capture at night, oppositely to the other plants performing photosynthesis. However, severe light limitation can affect CAM photosynthesis [15]. More details concerning the CO_2 pathway through CAM can be found elsewhere [16-19]). In this study, *Tillandsia* was able to adapt to the illumination conditions and to perform CO_2 capture in the presence of light. An acclimatization of few days in the presence of light was necessary to switch for this alternative

metabolism. Moreover, except a temporary plant response to the irrigation (i.e. CO_2 removal efficiency partially dropped, after which recovered back), the system response to the change in the experimental conditions was usually fast and stable (results not shown).

As can be seen in Figs. 2 and 4, RE_{CO2} decreases with the increase of the gas flowrate, the best performance (RE_{CO2} > 80%) being observed for both BF1 and BF2 at the smallest tested gas flowrate (0.015 L/min), when a better gas-plant contact is favored allowing a more efficient CO_2 capture. Doubling the number of the plants in the column reactor slightly increases the process performance (Figs. 2 and 5). At higher plant densities a shading effect can occurs, which might reduce the amplitude of their favorable influence on CO_2 capture. This drawback could be overcome by further enhancing the illumination conditions (e.g., light intensity, number of lamps). On the other hands, a stabilization trend in CO_2 capture is observed at light intensities above 20 klux. These aspects indicate that further increasing the light intensity (e.g., above 20 kLux) doesn't necessarily improve the process performance, and in this case a higher number of lamps can be considered. The negative RE_{CO2} values indicates formation of CO_2 and usually occurs in dark (Figs. 3 and 5).

Moreover, from the gas composition point of view, it can be observed (Fig. 6) that the O_2 level in the processed gas was not affected by CO_2 reduction in the system, although some increase in water content is noticed.

These promising results shows the opportunity of using *Tillandsia* sp., particularly *T. xerographica*, in air biofiltration. The use of a single plant type (e.g., *T. xerographica*) allows a better process control, but a mix of plants can be considered as well, depending on the application purpose. *T. xerographica* is a clean soil-free plant, easy to manipulate, being able to resist on long-term under different environmental conditions, with a minimum requirement in terms of water and nutrients. Further research needs refer to exploring more the capabilities of this aerial plant to perform other gaseous contaminants removal, as well.

5. CONCLUSIONS

This study is moving forward the use of aerial plants in air purification such as *Tillandsia* sp., particularly *T. Xerographica*. These plants exhibited promising results in terms of CO_2 removal and similar results are expected when referring also to other gaseous contaminants removal as well. Several conclusions are drawing during this study such as:

- The highest CO_2 removal performance (RE_{CO2} > 80%) occurred at the minimum gas flowrate and the maximum illumination, which can be further subject to the number of plants involved in the biofilter for minimizing the shading effect.

- Both individual (e.g., *T. xerographica*) as well *Tillandsia* mix exhibited promising performances in CO_2 removal.

- The investigated botanical biofiltration process was not affecting the oxygen level from the processing gas.

- One of *Tillandsia* sp. advantage is its use as it is, without any soil involvement and a minimum nutrients/water requirements, which make them extremely attractive in many applications.

Future research refers to the investigation of *Tillandsia* sp (i.e., *T. Xerographica*) towards other contaminants removal in the light of possible special applications (e.g., mitigation of gaseous pollutants from auto traffic, space applications).

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REFERENCES

1. Filho, GMA, Andrade, LR, Farina, M & Malm, O 2002, Hg localisation in *Tillandsia usneoides L.* (Bromeliaceae), an atmospheric biomonitor, *Atmospheric Environment*, vol. 36, pp. 881–887.
2. Li, J, Li, P, Wang, H & Zheng, G 2013, Purification of air pollutant-formaldehyde with special plant group-epiphytic *Tillandsia*, *Chinese Journal of Environmental Engineering*, vol 7, pp. 1451–1458.
3. Li, P, Pemberton, R & Zheng, G 2015, Foliar trichome-aided formaldehyde uptake in the epiphytic *Tillandsia velutina* and its response to formaldehyde pollution, *Chemosphere*, vol. 119, pp. 662–667.
4. Kim, JJ, Park, J, Jung, SY & Lee, SJ 2020, Effect of trichome structure of *Tillandsia usneoides* on deposition of particulate matter under flow conditions, *Journal of Hazardous Materials*, vol. 393, art. 122401.
5. Granados Mendoza, C, Salazar, GA & Flores-Cruz, M 2016, A New Species of the Mexican *Tillandsia erubescens* Group (Bromeliaceae), *Phytotaxa*, vol. 260, pp. 57–65.
6. Estrella-Parra, E, Flores-Cruz, M, Blancas-Flores, G, Koch, SD & Alarcón-Aguilar, FJ 2019, The *Tillandsia* genus: history, uses, chemistry, and biological activity, *Boletín latinoamericano y del Caribe de plantas medicinales y aromáticas*, vol. 18, pp. 239–264.
7. Papini, A, Tani, G, Di Falco, P & Brighigna, L 2010, The ultrastructure of the development of *Tillandsia* (Bromeliaceae) trichome, *Flora*, vol. 205, pp. 94–100.
8. Cach-Perez, MJ, Andrade, JL & Reyes-Garcia, C 2018, Morphophysiological Plasticity in Epiphytic Bromeliads Across a Precipitation Gradient in the Yucatan Peninsula, Mexico, *Tropical Conservation Science*, vol. 11, pp. 1–10.
9. Stefano, M, Papini, A & Brighigna, L 2008, A new quantitative classification of ecological types in the bromeliad genus *Tillandsia* (Bromeliaceae) based on trichomes, *Revista de Biologia Tropical*, vol.56, pp, 191–201.
10. Pellegrini, E, Lorenzini, G, Loppi, S & Nali, C 2014, Evaluation of the suitability of *Tillandsia usneoides* (L.) L. as biomonitor of airborne elements in an urban area of Italy, Mediterranean basin, *Atmospheric Pollution Research*, vol. 5, pp. 226–235.
11. Martínez-Reséndiz, G, Lucho-Constantino, CA, Vázquez-Rodríguez, GA, Olivares, CC & Beltrán-Hernández, RI 2015, *Tillandsia usneoides* as biomonitor of air pollution, *Asian Academic Research Journal of Multidisciplinary*, vol. 2, pp. 262–285.
12. García, M & Ordóñez Chocano, H 2008. Case study: *Tillandsia xerographica*. Available at: https://cites.org/sites/default/files/ndf_material/WG2-CS7.pdf
13. Convention on International Trade in Endangered Species of Wild Fauna and Flora. Available at: https://cites.org
14. Soreanu, G, Mardari C, Tanase C, Volf I, Lazar L & Cretescu, I (2022). Carbon dioxide reduction potential of some plants involved in the removal of air pollutant mixtures by biofiltration. *Ecology & Safety*. (*submitted*)
15. Ceusters, J, Borland, AM, Godts, C, Londers, E, Croonenborghs, S, Van Goethem, D & De Proft, MP 2011, Crassulacean acid metabolism under severe light limitation: a matter of plasticity in the shadows? *Journal of Experimental Botany*, vol. 62, no. 1, pp. 283–291, doi:10.1093/jxb/erq264.
16. Ceusters, N, Borland, AM & Ceusters, J 2021, How to resolve the enigma of diurnal malate remobilisation from the vacuole in plants with crassulacean acid metabolism? *New Phytologist,* 229, pp. 3116–3124, doi: 10.1111/nph.17070.

17. Lin, Q, Abe, S, Nose A, Sunami, A & Kawamitsu, Y 2006, Effects of High Night Temperature on Crassulacean Acid Metabolism (CAM) Photosynthesis of Kalanchoë pinnata and Ananas comosus. *Plant Production Science*, 9:1, pp. 10-19, DOI: 10.1626/ pps.9.10.
18. Winter, K, Holtum, JAM & Smith, JAC 2015, Tansley insight -Crassulacean acid metabolism: a continuous or discrete trait? *New Phytologist*, 1-6. doi: 10.1111/nph.13446.
19. Lim, SD, Lee, S, Choi, W-G, Yim, WC & Cushman, JC (2019) Laying the Foundation for Crassulacean Acid Metabolism (CAM) Biodesign: Expression of the C4 Metabolism Cycle Genes of CAM in Arabidopsis. *Frontiers in Plant Science,* 10:101, doi: 10.3389/fpls.2019.00101.