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Carbon Dioxide Sinks From Several Mexican Plants

Enrique Barrera-Calva[1*], Víctor Rentería-Tapia[2], Gloria Martínez[3] and Enrique Zeferino Barrera-Vargas[1]

[1]*Autonomous Metropolitan University-Iztapalapa, Mexico City 09340, Mexico.*

[2]*Department of Natural and Exact Sciences, University of Guadalajara-CUVALLES, Ameca 46600, Mexico.*

[3]*Department of Chemical Engineering, Technological Institute of Celaya, Celaya 38010, Mexico.*

***Corresponding author**

Enrique Barrera-Calva,
Autonomous Metropolitan University-Iztapalapa, Mexico City 09340, Mexico.

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Abstract

This study examines CO_2 sinks and emissions of various Mexican plants as a function of the received solar irradiance. We also show measurements of pollution of particle sinks as a function of irradiation time for each monitored plant. The kinetics, profiles of CO_2 and particle evaluated concentrations are interpreted to estimate the photosynthesis rate. This estimation determines the net biomass yield of a system as a function of solar irradiance. These plants contribute to the thermal mitigation and improve air quality in indoor spaces, highlighting their essential role in enhancing indoor environments. Beyond their CO_2 dynamics, the plants' ability to filter particulate pollutants positions them as valuable assets for improving air quality in enclosed spaces. This aligns with the broader benefits of indoor plants in moderating indoor temperature and humidity, contributing to overall comfort and health.

Keywords: CO_2 sinks, particle matter, Mexican plants, kinetics.

Introduction

The world currently faces significant challenges due to increase in the concentration of CO_2 in the atmosphere when levels exceed to 400 ppm, along with other Greenhouse gases, they contribute to the threat of global warming on the planet. The increase in these gases leads to a notable rise in the average temperature of the atmosphere (~1 ^{0}C per century), attributed to the large heat capacity of the air. This effect endangers the humanity's survival due to the climate change associated with global warming (Carmona, 2013). Against this background, many societies have considered that trees themselves, soil, seas, and living organisms in nature constitute the sink for the enormous amounts of anthropogenic CO_2 emissions from the energy, agricultural and technological activities. However, it is known that mature plants or trees are capable of absorbing only about 100 kg of CO_2 per year, in contrast with an average foot print of a modern man reaching more than 1 ton of CO_2 /year. This constitutes a limitation in the face of the large increase in emissions of this gas into the atmosphere caused by the growing population and the increasing energy needs per capita, which reach around 320 KWh per person per day (Cook, 1971). Considering this limited capacity of nature, technological strategies are already being investigated to mitigate the concentration of CO_2 and other gases in the atmospheric composition, such as the development of artificial trees or other approaches that are still very expensive. The installation and operation of these devices require liquefaction of those gases, which entails high energy costs, around $600 dollars/Ton CO_2 (Campillo, 2024). At the domestic level there are some proposals to mitigate gaseous pollutants emitted inside rooms through plants; however, little information exists on the possible mechanisms of how plants can help in those tasks (Pvcase, 2024). Therefore, the study of some natural phenomena such as the photosynthetic processes of plants and their effects on the absorption or emission of CO_2 is very important. Scientific instruments enable engineers to understand and quantify these phenomena, as well causes and effects related to anthropogenic CO_2 emissions and to apply these processes in various technological fields, such as the environment, agrovoltaic sector, indoor air conditioning, etc. (Kimball, 1983; Turk, 2004; Morison & Lawlor, 1999).

Certain plants are particularly effective at reducing specific indoor pollutants, as evidenced by decreased concentrations of PM2.5 and PM10 particles (particulate matter with aerodynamic diameters ≤2.5 µm and ≤10 µm, respectively). To account for these changes, the ideal gas law is applied to adjust pollutant gas concentrations based on temperature and pressure (Eq. 1), (Municipalidad Distrital de Miraflores, 2024). In this equation: PPM represents the gas concentration in parts per million; mc is the gas mass; Va is the air volume; R is the universal gas constant; Mc is the molecular weight of the gas; T is the absolute temperature, and P is the atmospheric pressure.

$$PPM = \left(\frac{mc}{Va}\right)\left(\frac{R}{Mc}\right)\left(\frac{T}{P}\right)x10^6 \qquad (1)$$

This equation, [1] suggests that air pollution levels increase as atmospheric pressure decreases, a phenomenon commonly observed in high-altitude cities where atmospheric pressure is naturally lower. Similarly, pollutant concentrations tend to rise with increasing temperatures. In contrast, cities at sea level, characterized by higher atmospheric pressure, or conditions involving lower temperatures, typically experience reduced pollutant concentrations.

In this work, we demonstrate that the concentration profiles of CO_2 within an isolated system containing an evapotranspirant plant are influenced by solar radiation absorption. As the plant absorbs solar energy, it heats the entire controlled volume, leading to an increase in temperature, and the photosynthesis occur, consequently, a decrease in CO_2 concentrations. The results also hold significant relevance in understanding the role that plants can play within indoor spaces, which are increasingly found in urban homes, as a climate alternative to air conditioners.

Materials and Methods

The concentration of CO_2, particulate matter PM2.5, and PM10 were estimated in a transparent sampling box containing plants exposed at different solar irradiance conditions. Furthermore, data and interpretations of certain parameters obtained from plants in their net biomass production process. The rectangular box-type chamber was fabricated from methyl methacrylate (acrylic) with dimensions of 0.4x0.4x0.75 m, providing a test volume where each plant is placed in 1 kg of soil. The equivalent biomass volume was similar for all plants, projecting a comparable horizontal area of 0.25 m^2. Calibrated instruments were used to measure the CO_2 concentration, temperature and relative humidity. An Amprobe CO_2-200 instrument with a resolution of 1ppm was used for CO_2 concentration measurements. For PM2.5 and PM10 particle measurements an Aeroqual Series 500 instrument with a resolution of 1ppm was used. An Eppley model 8-48 pyrometer was used to measure the solar irradiance levels on a horizontal surface. Figure 1 shows a picture of the experimental setup.

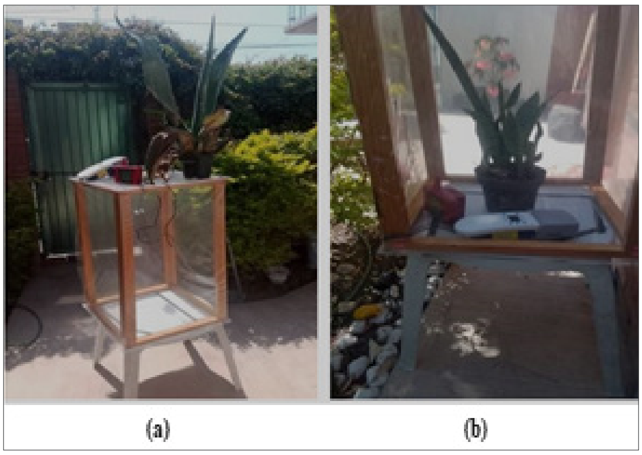

Figure 1: (a) Experimental setup with the test plant and measuring instruments located outside the fixed, airtight volume box;
(b) Test plant and measuring instruments within experimental setup.

To observe the tightness of the system, a CO_2 and particle profile as a function of time was measured in an empty box for several hours. Under these conditions, the CO_2 concentration remained stable during the test period probabily because gases do not have chance to sedimentation; while the particle concentration PM10 and PM2.5, decreased by around 33% of the initial value in approximately 24 hours. Our test box maintained the concentration of gas, but not that of particles due to sedimentation processes into the internal face of the chamber, which decreased the original concentration.

After conducting the empty test of the system, the test plants were placed one by one. CO_2, particle, as well as the temperature, relative humidity and the solar irradiance profiles were measured during direct exposing in periods 24 to 48 h. These measurements were recorded manually every 5, 10 or 15 minutes. In the experimental tests, it was sought that the characterized plants had similar biomass. The plants were grown with the same mass of soil (1 kg) and having a same height plant h (Figure 2). It was also intended to ensure that the projected area of the plant on the horizontal plane had a circle of equal diameter.

In some experiments, the test system was placed in a room where sunlight was directed through a system of mirrors. This setup aimed to measure the parameters of interest under conditions of fixed solar irradiance, 85 W/m2 for some plants and 60 W/m^2 for others. According to the hypothesis, the concentration profiles of each plant behave more stable under sunlight, where the photosynthetic process is enhanced. At lower irradiances, including zero values, the plant begins to emit more CO_2 than it consumes. The results of some representative profiles of each plant are shown in the following section, along with those obtained under Fixed Solar Irradiance.

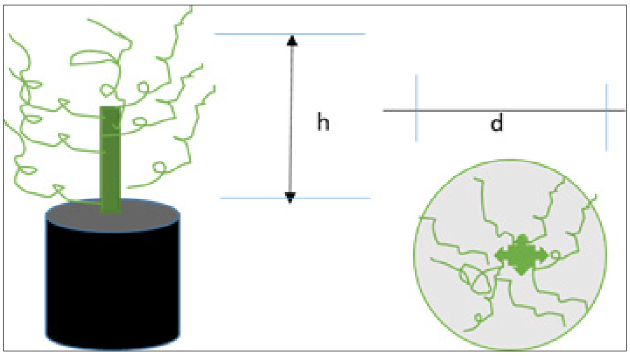

Figure 2: Scheme of the test plant arrangement showing height h and biomass projection on the horizontal plane in a circle of diameter *d = 40 cm*, which is equivalent among plants. The left scheme illustrates a plant height of h=45 cm, while the right one depicts the projected area of the plant on the horizontal plane in a circle of similar diameter. Each plant was provided with an equivalent amount of soil (1 kg per plant).

Results and Discussion

CO_2 Profiles for *S. trifasciata*

On various days in December 2023, January and February 2024, different CO_2 concentration profiles and particle amounts, including PM2.5 and PM10, were registered inside the box, as a function of time for different test plants. Additionally, indoor temperature, relative humidity % and the solar irradiance levels (W/m^2) on the horizontal of the place, were measured. Figure 3 shows the representative results of the CO_2 concentration profile in ppm for the mother-in-law's tongue plant Sansevieria trifasciata (*S. trifasciata*), as well as the levels of solar irradiance, as a function of time.

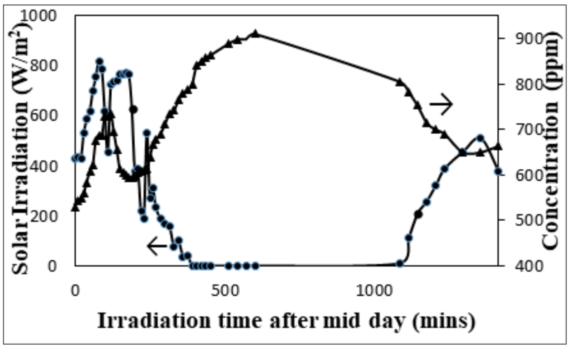

Figure 3: Representative data for the CO_2 concentration profile in ppm for the mother-in-law's tongue plant (*Sansevieria trifasciata*), and levels of solar irradiance in W/m^2 as a function of time.

Solar irradiance conditions are influenced by the cloudiness of the site, which is why the ups and downs of CO_2 concentration are noticeable. In Figure 3, in general, CO_2 sinks are observed, when solar irradiance increases, but emission stages are also presented, observed by increases in CO_2 concentration in the system, when levels of solar irradiance decrease, reaching values maximums during the night. When looking in Figure 3, two large drops in the CO_2 concentration are observed towards the first minutes of the experiment, which began around noon civil time at the site, and then several hours after the first drop. In fact, at the beginning of the next day, decreases in CO_2 concentration are also common, which is related to the increasing value of incident irradiance in the test plant.

The results are important, because any cloud cover or shading, such as the shading of solar photovoltaic installations in agrovoltaic systems, will be crucial in the estimating the kinetics of CO_2 emissions or sinks, and therefore in the thermal efficiency of the net biomass estimate of the plants. A typical CO_2 sink shown after a cloud shading stage is amplified in Figure 4. Another important sink occurs in the morning, in the first hours after dawn, as shown in Figure 5.

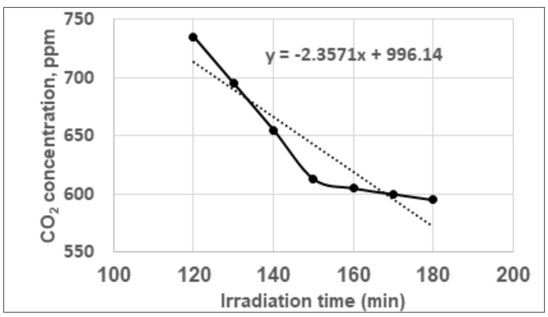

Figure 4: CO_2 sink occurring after passing a cloud cover, with a suddenly appearing of intense sunlight. The rate of CO_2 decreases as a function of irradiation time can be estimate from the slope of the fitted line, (CO_2 sink kinetics).

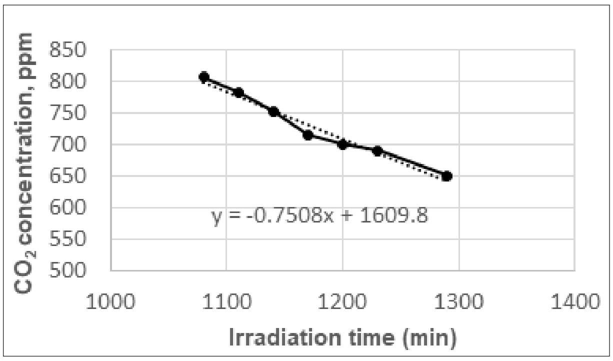

Figure 5: CO_2 sink occurring at the morning of the next measurement day, with intense and increasing solar irradiance.

From these figures, an adjustment line is drawn to represent the decrease in measured CO_2 and its equation is estimated. The slope of this line represents the CO_2 sink rate (negative value) over time, with units (ppm/minute). A greater absolute value of this slope roughly indicates a stronger photosynthetic process in the plant under study. However, high irradiance can damage the photosynthesis process, when the light intensity exceeds the plant's carbon cycle. Fortunately, plants have several defense mechanisms to counteract this, such as energy dissipation and fluorescent inactivation.

The variation of CO_2 as a function of the irradiation dose I in the linear region of interest, can be inferred according to next equations:

$$d[CO_2]/dt = k1 \quad (2)$$

$$dI/dt = k2 \quad (3)$$

$$d[CO_2]/dI = k1/k2 \quad (4)$$

$$[CO_2] = (k1/k2)*I + constant = K*I + c \quad (5)$$

It is clear that K value is always negative in the sinks and the CO_2 concentration only depends on the I value and of the constant c. The results suggest that a minimum irradiance level is required for the photosynthetic process to proceed and the initial conditions determined by the c value. Similarly, as the irradiance increases, a saturation limit is reached, which dependent on the plant leaf structures and consequently limited CO_2 capture. In this regard, CO_2 sinks are more efficient in ferns compared to the other two plants as will be discussed next.

It is possible to estimate CO_2 emissions over irradiation time. Figure 6 highlights a selected range of this behavior, previously observed in Figure 3. This analysis typically occurs when solar irradiance decreases due to shading or cloud cover at the sample plant's location. A graphical fit of the emission process is also adjusted to a straight line, enabling the determination of the CO_2 emission rate over time, which corresponds to the slope of the fitted line.

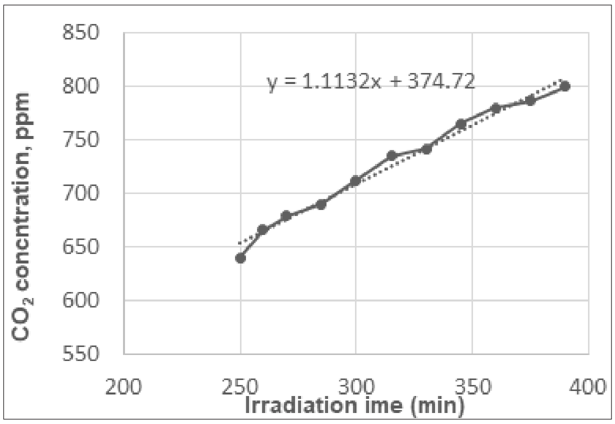

Figure 6: CO_2 evolution graph, occurring during heavy cloud cover. From this graph, the rate of CO_2 evolution as a function of irradiation time could be estimate from the slope of the fitted line to this data.

CO2 Profiles for other Plants

Figure 7 shows a typical CO_2 sink and emission profile as a function of time for another representative plant Agave Salmiana (Maguey) in this study. In this case, we start from an experiment where the initial concentration of CO_2 inside the box is higher than the external concentration. This difference increases over time of exposure in a day particularly with high cloud cover. Later, as the day clears and as the solar irradiance increases, a strong CO_2 sink occur. For longer measurement time, more emission and sink cycles are seen. From the most representative profiles, a linear profile is adjusted, which allows the calculation of sink and emission rates.

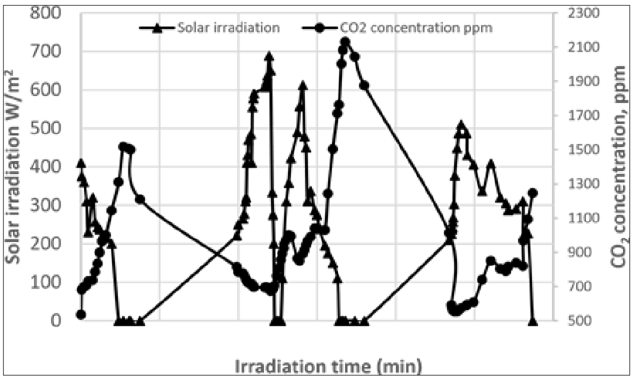

Figure 7: CO_2 concentration profile in ppm and solar irradiance as a function of irradiation time for a maguey plant, Agave Salmiana, after starting the experiment at the noon of the day

If we put the simplified reaction of photosynthesis into context (Equation 6), it is observed that plants, usually in the presence of sunlight, use atmospheric CO_2 to synthesize glucose molecules and also oxygen. The energy efficiency of this reaction is very low, <<1%, and it is an objective to find better species or chemical mechanisms to achieve an increase in the net production of plants. The sustainability of this reaction is greatly favored by sunlight, however the reversible nature of this reaction also teaches that in the absence of light or in darkness, plants can usually be generators of CO_2 by metabolizing glucose molecules, for their own survival. It is known, through these types of studies, that plants are also an important sink for particles present in the atmospheric air.

$$6CO_2 + 6\,H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6\,O_2 \quad (6)$$

Table 1 shows a summary of the rate of these most relevant profiles including third plant, corresponding to a fern (Pteridium aquilinum) and its highest measured photosynthetic rates.

Table 1: Net CO_2 sink (ppm/min) and CO_2 emission rates for three plant species as a function of time.

Plant (ppm/min)	Sink(ppm/min)	Emission
Mother-in-law's tongue plant, *S. trifasciata*	2.35	1.11
Maguey, agave Salmiana	2.39	3.21
Fern, Pteridium Aquilinum	2.64	1.31

In particular, Figure 8 presents a typical particle profile of PM2.5 and PM10 for a maguey plant, which consistently shows a downward trend with an exponential decline, indicating very low particle concentrations inside the sample box. The particle sink rate was estimated in the initial region of the curve, where a linear profile represents the maximum particle removal rate for three different plant species. The estimated sink rates for these species are summarized in Table 2.

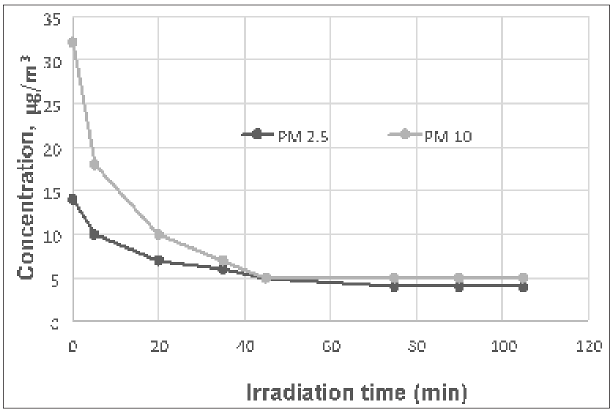

Figure 8: Profile of the sink concentration of particles PM 2.5 and PM 10 for maguey plant (Cactus).

It is observed that plants exhibit a characteristic sink rate for each specie, which may explain why they are considered sinks for certain organic and volatile substances in indoor environments, as studied by NASA and other important research centers. This particle diminution is very relevant for environmental purposes within rooms and for interior conditioning processes, which have been very few studied and that demand systematic knowledge of these parameters.

On the other hand, the structure of plant leaves has a very important effect. For example, Maguey can reduce the concentration of PM10 material 3 times more than PM2.5, while the ratio of PM2.5 to PM10 for the other plants is almost constant = 0.8. This may be due to the multiple and large stomata and cuticular layer of the maguey, which are not observed in the other two plants.

Table 2: Net sink rates of PM 2.5 and PM10 particles for three plant species as a function of irradiation time.

Plant	PM2.5, ($\mu g/m^3$/min)	PM10, ($\mu g/m^3$/min)
Mother-in-law's tongue plant, *S. trifasciata*	0.281	0.343
Maguey, agave Salmiana	0.119	0.315
Fern, Pteridium Aquilinum	0.274	0.331

An experiment that was also carried out consisted of inside sunlight directly on the plant, through a system of mirrors, avoiding overheating in the measuring equipment itself and in the total gas volume of the box. This seems be a more controlled way for the incidence of solar energy on the plant. It was possible to obtain CO_2 sink curves and also the evolution of the gas, when direct light ceased to occur, (see Figure 9), which corresponds to an incident irradiance through several mirrors fix at approximately (85 ± 5) W/m^2.

From Figure 9, a linear adjustment was made to the representative experimental results. Based on this adjustment the CO2 sink rate and its evolution as a function of time (after cessation of solar irradiation) are estimated for a fixed total solar irradiance (Figure 10). On the other hand, Table 3 shows the sink and evolution rates of CO_2, for two values of fixed total solar irradiance across the three studied plants.

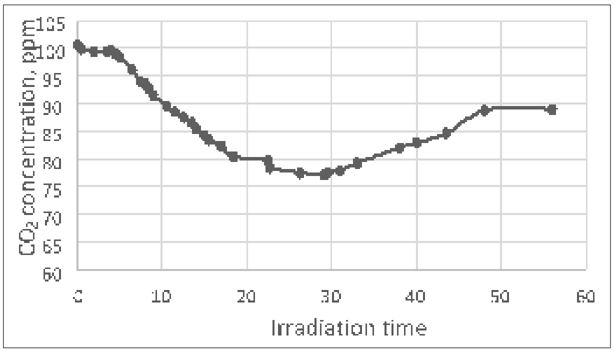

Figure 9: CO_2 concentration at a fixed solar irradiance (Is=85 W/m2) for Maguey in the CO_2 zone sink showing an increase after cessation of irradiation.

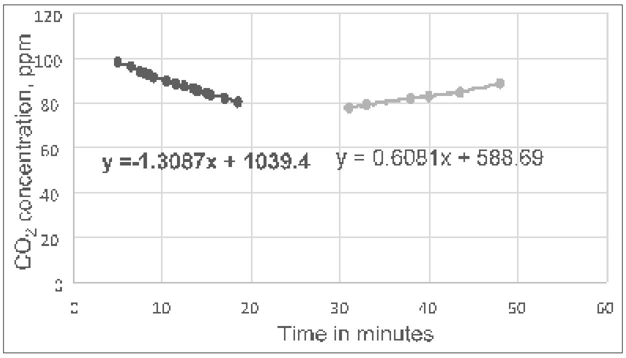

Figure 10: CO_2 concentration at fixed solar irradiance exposure time for Maguey (Is=85 W/m^2). A linear fit for CO_2 emission is shown in specific range of irradiation time, after avoiding solar irradiance.

Table 3: Sink rates and net CO_2 emission, as a function of irradiation time, at two fixed values of total solar irradiance, for the three plants studied.

Plant	Sink and emission, (ppm/min) Is = 85 W/m^2	Sink and emission, (ppm/min) Is = 60W/ m^2
Mother-in-law's tongue plant, *S. trifasciata*	1.32; 0.633	0. 49; 0.202
Maguey, agave Salmiana	1.30; 0.608	0.47; 0.197
Fern, Pteridium Aquilinum	1.43; 0.702	0.517; 0.213

Conclusion

The experimental study of the sink profile and CO_2 emission by some plants is very important, since when carrying out the measurements, it was found that the environment of the plants within an air control volume allows increases and decreases in the surrounding CO_2 concentrations, as a function of the solar irradiation incidence, as well as allowing us to observe a notable decrease in PM 2.5 and PM 10 particles in the air at a very low level in relation to clean atmospheric air. This shows that the particle or gas interaction with the plant are very relevant.

This prompts us to reflect that in cities like CDMX, México, given the economic adversities, but even the climatological ones, they are sometimes a disadvantage in finding a sustainable environmental and ecological scenario. It is essential for people to continue increasing the number of green areas. Therefore, as a proposed aim, houses or concrete area must be purchased in the city, changing the soil uses to increase green areas. We need to reach and even exceed the rate recommended by the UN of reaching 10 m^2 of green area per inhabitant in CDMX. There is an environmental disadvantage of cities with higher elevations, Mexico city, where lower atmospheric pressure, can be lead to an increased concentration of atmospheric pollutants.

In this experimental study, we observe a sink of greenhouse gases as well as very noticeable particles in the air, so the role of plants in air quality and or in some important mechanisms such as the sequestration of atmospheric carbon, are very relevant. This simple study opens up a range of possibilities for identifying species that provide the highest rate of carbon sequestration, under certain conditions of natural solar irradiance. Such studies should continue to be conducted on potentially useful plants and considered in the environmental and agrovoltaic strategy, for better optimization of this new energy-engineering scheme.

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