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Use of compost and biochar for the improvement of the quality of urban soils in the framework of an exhibition with public participation.
Ús de compost i biochar per a la millora de la qualitat de sòls urbans en el marc d'una exposició amb participació ciutadana.

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A tots els que, d'una manera o altra, han format part d'aquest projecte.

REPORT

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1. SUMMARY

In the framework of the exhibition “After the end of the world”, held by the *Centre de Cultura Contemporània de Barcelona*, an urban space was set up as the basis of the Environmental Health Clinic of the engineer and artist Natalie Jeremijenko. Participatory activities were organized in terms of improvement of environmental health, including the enhancement of the quality of the soil by the use of amendments. Urban soils frequently have a low quality that hampers vegetation growth. Several properties, e.g. compaction and water holding capacity (WHC), can be redressed by the application of amendments. In this context, a field experiment was developed to assess the adjustment of soil quality by the addition of compost (C) and biochar (B) to a poor urban soil. Aiming at public participation, a simple method to visualize the effect of these amendments in soil properties was set up to be carried out by the people attending the exhibition.

In the field experiment, treatments included C, B and C + B at three different proportions each. The assessed parameters were bulk density, pH, humidity, WHC and organic matter content (OM). Bulk density showed a decrease for all the treatments, being more drastic at rising proportions of amendment. The alkaline pH of the soil was lowered by the addition of C and C + B, whilst B slightly increased it. WHC was determined following the set up method, which showed reliable differences between samples. The WHC showed a relation with the OM, explained by the increased retention of moist caused by organic matter. Humidity and WHC followed the same tendency showing an increase for all treatments applied, being the effect larger for C than for B.

The applied treatments showed a tendency to the improvement of soil properties, with increasing benefits at rising proportions of amendment. The combination of biochar and compost might lead to a higher enhancement. Thus, the addition of amendments to the soil could result in more optimal conditions for vegetation growth in urban areas.

Keywords: biochar, compost, soil quality, exhibition, public participation

2. RESUM

En el marc de l'exposició "Després de la fi del món", organitzada pel Centre de Cultura Contemporània de Barcelona, l'enginyera i artista Natalie Jeremijenko ha establert la seva Clínica de Salut Mediambiental. Es tracta d'un espai amb participació ciutadana on s'han dut a terme activitats enfocades a la millora del medi ambient, incloent la millora de la qualitat del sòl mitjançant l'ús d'esmenes. La baixa qualitat dels sòls dificulta el creixement de la vegetació en zones urbanes, i l'aplicació d'esmenes pot implicar una millora en moltes propietats, com ara la compactació i la capacitat de retenció d'aigua (WHC). Amb aquest objectiu, s'ha desenvolupat un experiment de camp per avaluar la millora de la qualitat del sòl mitjançant l'addició de compost (C) i biochar (B) en un sòl urbà empobrit. En el context de l'exposició, s'ha posat a punt un mètode senzill perquè els visitants de l'espai puguin visualitzar l'efecte d'aquestes esmenes.

En l'experiment de camp, els tractaments aplicats han sigut C, B i C + B, cadascun d'ells en tres proporcions diferents. Els paràmetres estudiats han sigut la densitat aparent, el pH, la humitat, la WHC i el contingut de matèria orgànica (OM). La densitat aparent ha mostrat una disminució per tots els tractaments, essent més evident a proporcions creixents d'esmena. L'elevat pH del sòl s'ha vist disminuït amb l'aplicació de C i C + B, mentre que l'aplicació de B n'ha provocat un lleuger augment. La WHC s'ha determinat seguint el mètode posat a punt, que ha permès observar clares diferències entre les mostres. La WHC ha mostrat una relació amb la OM, fet explicat per la major retenció d'aigua causada per la matèria orgànica. Humitat i WHC han seguit la mateixa tendència mostrant un augment per tots els tractaments, essent aquest més accentuat per l'aplicació de C que per la de B.

Els tractaments aplicats han mostrat una tendència a la millora de la qualitat del sòl, amb beneficis més evidents a majors proporcions d'esmena. La combinació de biochar i compost podria ser l'opció més favorable. Es conclou que l'aplicació d'esmenes pot derivar en condicions més òptimes pel creixement de la vegetació en zones urbanes.

Paraules clau: biochar, compost, qualitat del sòl, exposició, participació ciutadana

3. INTRODUCTION

3.1. CONTEXTUALIZATION

This project is part of the exhibition “After the End of the World”, held by the museum Centre de Cultura Contemporània de Barcelona. The exhibition (CCCB, 2017) presents the Earth’s situation in 2017, and poses a major problem: after two centuries of human impact on natural systems the world has irreversibly been transformed into the Anthropocene planet, and it is our responsibility as a society to take action to avoid the emergency situation coming up, derived from the climate crisis. Different artists show their point of view and expose possible futures derived from it, emphasizing the devastating consequences.

In addition to the museum rooms, another space has been defined within the exhibition: City Station is an open-air laboratory space that has been set up by the engineer and artist Natalie Jeremijenko as the basis of her Environmental Health Clinic, with a red “X” as a symbol. The space, located in the district of Sant Martí (passatge Trullàs s/n, Barcelona), empowers the citizenship to take action to remediate the low quality of the surrounding environment, as it is an area with poor soils, polluted air and no vegetation, and the need of its enhancement is clear. In the walls surrounding the space vertical gardens have been built in, which are hanging structures used to grow plants to remedy the lack of ground space. Additional infrastructures share the space where participatory activities are performed. To do so, a series of recipes have been prepared by Doctors X, experts without disciplinary boundaries who commit with the project by making recipes related with their field of knowledge. Recipes are followed by citizens to perform in a particular area, e.g. enhancement of soil quality and green areas, measurement of air pollution, measures on biodiversity or reduction of energy consumption.

3.2. URBAN SOILS

Green areas are mandatory to ensure a good quality of life in cities, as they allow air renovation and have a therapeutic function for people. Moreover, these areas are home to a lot of animal and vegetal species, so it is important to have soils of good quality that can hold and maintain these areas.

Urban soils frequently have a low quality that hampers vegetation growth, with all the devastating consequences this has in the quality of city life. They present a high compaction that lowers water holding capacity (WHC) and nutrient retention. Moreover, soils that in the past were occupied by industrial activities also tend to be contaminated by heavy metals. These problems need to be minimized as their consequences are extensive and difficult to redress. Amendments can be used to improve soil quality.

In the framework of the CCCB exhibition, one of the experiments of City Station was to study the effect of compost and biochar to adjust the quality of an urban soil. Compost and biochar were applied to a plot containing poor soil to measure their effect in soil properties and their capacity to enhance plant growth.

3.3. COMPOST

Compost is the result of decomposed organic matter in a process where complex organic forms are degraded into simpler ones. Ideal materials to make good compost have 60 – 70 % moisture and are rich in nutrients (International Biochar Initiative, 2017).

It is used to adjust soil quality, as its application results in a short-term improvement of soil properties such as nutrient content and cation exchange capacity (CEC). Some studies suggest these properties are enhanced when mixing compost with biochar (Schulz et al., 2012). Environmental benefits of the use of compost as an amendment include the retention of heavy metals, thus it can be used to remediate contaminated soils (Venegas et al., 2015; Venegas et al., 2016).

3.4. BIOCHAR

Biochar is the solid phase obtained from the pyrolysis of biomass. Although it is a high energy material that can be burned (~18 MJ kg^{-1}), it is intended to be used for environmental purposes, as when applied to the soil it results in significant agronomic and environmental benefits (Laird et al., 2009).

3.4.1. History

The practice of using biochar as a soil enhancer seems to have its origin in *Terra Preta*, a region by the watershed of the Amazonian river. Although soils in the tropics are thought to be infertile, there is strong evidence that these soils supported sustainable agriculture. The enhanced fertility is attributed to higher levels of soil organic matter (OM), nutrient content, WHC and pH. These properties, provided by biochar, have persisted for centuries after the native population left the area (Glaser et al., 2001).

3.4.2. Production

Biochar is obtained through pyrolysis, a process in which biomass is subjected to high temperatures with limited supply of oxygen (figure 1). Biomass decomposes with release of biochar, bio-oil and syngas. Whereas traditional systems let volatiles vent to the atmosphere, in modern pyrolyzers volatiles are reconducted to the pyrolysis chamber to provide the required energy for the process (Laird et al., 2009). Pyrolysis conditions such as temperature and duration, together with the biomass source, have an important influence on the properties of biochar (Sohi et al., 2010).

Although almost any type of organic matter can be converted, the presence of some materials such as ash or inorganic compounds can be unfavourable to the process (Laird et al., 2009). In addition, low moisture feedstocks are preferred as there is no need to use energy to dry them (International Biochar Initiative, 2017). The purpose of biochar production is to potentiate the environmental and agronomic benefits of its application to the soil, so the production systems must be sustainable. Therefore, the biomass should be sourced from agricultural or forestry waste (Laird, 2008).

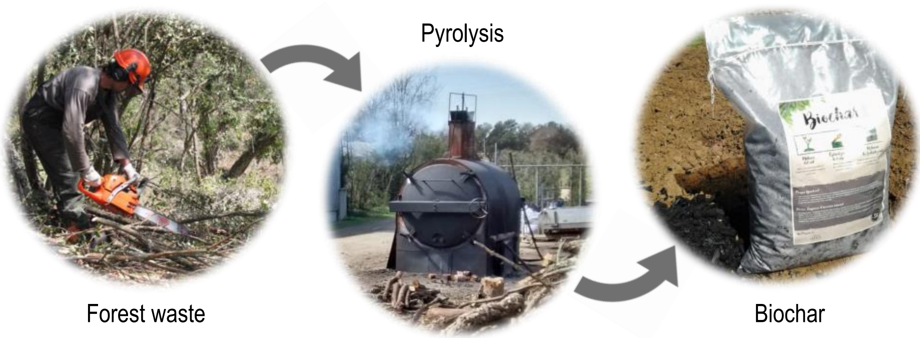

Figure 1. Production of biochar. Photos supplied by IDÀRIA SCCL (Empresa d'Inserció, Llagostera).

3.4.3. Properties

The properties of biochar provide a large list of environmental and agronomic benefits. These benefits suggest that the addition of biochar to the soils could be a strategy for long-term carbon sequestration while enhancing green areas (Lorenz et al., 2014; Schulz et al., 2012).

3.4.3.1. Agronomic benefits

Although its effects cannot be generalized because they depend on the type of biochar, soil and plant (Lorenz et al., 2014), numerous studies show the benefits of biochar as an amendment. It has been reported to increase nutrient retention, WHC, CEC and pH (Laird et al., 2009). It also helps to lower bulk density, which increases the drainage, aeration and root penetration (Laird, 2008). Biochar retains the nutrients contained by the biomass from which it originates, and it can slowly release them to growing plants (Laird, 2008). When mixed with compost it enhances its effects in soil (Schulz et al., 2012), as the interaction with compost leads to the adsorption of nutrients in its surface that can be slowly released to the plants. This improvement of soil properties results in the achievement of increased crop yields (Laird, 2008).

3.4.3.2. Environmental benefits

Biochar's adsorption capacity reduces the leaching of pollutants and agricultural chemicals to water (Laird, 2008; Laird et al., 2009). Studies have also shown its effect as a heavy metal holder (Doumer et al., 2016; Venegas et al., 2015; Venegas et al., 2016).

As it is a carbon rich material, environmental benefits are also related to the carbon cycle. Whilst compost is carbon neutral, because the carbon captured in the biomass by photosynthesis returns to the atmosphere through decomposition, biochar is carbon negative (International Biochar Initiative, 2017). This means that when converted into biochar, carbon captured in the biomass from which it proceeds can be retained in the soil for millennia (Laird, 2008). Currently, the production of biochar sequesters 0.1 – 0.3 Gt of carbon per year (Laird et al., 2009), so a large biochar production could mean a mitigation of climate change by reducing the amount of atmospheric CO_2 (Lorenz et al., 2014; Laird et al., 2009). Studies suggest it may also have other greenhouse gas benefits by altering the emissions of CH_4 and N_2O (Lorenz et al., 2014; Laird et al., 2009).

3.4.4. Scenario

The use of biochar as an amendment has problems to overcome. The first one is economics. Energy companies are paid by the fuel delivered, so the biochar produced would preferably be burned to be economically viable (Laird, 2008). Moreover, the incentive of applying biochar to the fields is small because the investment will not be recovered for a few years (Laird, 2008). In spite of this, the long-term benefits are significant. The fields with biochar acquire value through increased crop yields, reduced need for fertilizers and increased land values (Laird et al., 2009).

Another important problem is the lack of the technology required to manage the biochar while transporting it and incorporating it to the soils. Biochar needs to be carefully handled as the dust generated, together with the possible undesired emissions from mishandling of the pyrolyzers, could contaminate the air and lead to to human health problems (Laird, 2008).

Although studies show numerous benefits related to the application of biochar to the soils, there are still important issues to work on. To overcome these difficulties more research is needed in many fields: technological aspects such as improvement of pyrolyzers and development of systems for biochar management, and agricultural aspects such as verifying and quantifying the benefits of biochar application to the soil. This project is aimed to contribute to this last aspect.

4. OBJECTIVES

This project had two main objectives. The first one was the assessment of the effect of compost and biochar as amendments in an urban soil, specifically:

- To assess the improvement of soil parameters due to the addition of biochar and/or compost to the soil at different doses, by means of a field experiment.
- To set up a simple method to determine in an everyday context the WHC of soil and soil + amendment and to check its reliability.
- To set the starting point in the quantification of the capacity of biochar and compost to enhance plant growth.

The second objective was the implementation of the set up method as an activity in City Station, in terms of improvement of environmental health. Specific objectives were:

- To disseminate information about biochar, its properties and its environmental effects.
- To bring science closer to people by writing and performing Doctor X recipes.
- To enhance the participatory disclosure in a distended space by doing workshops with students.

5. MATERIALS AND METHODS

5.1. MATERIALS

5.1.1. Soil

The purpose of the project was to enhance the soil from the emplacement of City Station. The CCCB had several difficulties finding an emplacement for City Station and they even had to renounce to two places. The final site was laid to concrete. In the absence of available soil to plant, we had to simulate the scenario and add soil of the required characteristics. The soil (S) was provided by the gardening company Buresinnova S.A. (Mercabarna Flor, Sant Boi de Llobregat). It consisted of weathered granodiorite parent rocks, including mica, feldspar and quartz, sieved at 10 mm. Its low nutrient and high sand content made it a poor soil that would present difficulties in allowing plant growth and sustaining vegetation.

5.1.2. Compost

The compost (C) was provided by the gardening company Buresinnova S.A. (Mercabarna Flor, Sant Boi de Llobregat). Raw materials were pruning waste, subjected to an aerobic composting process during an approximate period of 3 months.

5.1.3. Biochar

The biochar (B) was provided by IDÀRIA SCCL (Empresa d'Inserció, Llagostera). Raw materials were heath and oak, originating from fire prevention works in Gavarres and Ardenya Cadiretes, as these are the main species that can be found in these forests.

The pyrolysis process was done in a metallic furnace that allowed firewood to be separated from fire during the process. Firewood was placed in a closed chamber, and gases generated were redirected to the furnace to raise the temperature to 400 – 450 ºC. The pyrolysis process lasted for 7 hours, and the product was cooled in an oxygenless atmosphere for a further 7 hours.

5.1.4. Mixtures

Three types of mixtures were prepared: soil containing only biochar, soil containing only compost and soil containing both biochar and compost. For each one of the mixtures, three different proportions of amendment were established: low, medium and high. The mixtures were prepared *in situ* by taking big volumes of the materials and mixing them in the decided proportions using a concrete mixer. One aliquot of each mixture was put in a one-liter container to analyse in the lab.

Whereas proportions in field applications can be of 18 % (w/w) for compost and 2.5 % (w/w) for biochar (Mackie et al., 2015), these values were increased as the space City Station had a mainly artistic purpose, and observable changes were wanted in a short lapse of time. The acronyms used for the mixtures are described in table 1, as well as the volumes (V) of each material taken for their preparation:

Table 1. Acronyms for the mixtures and their composition.

Acronym	Description	$V_{Amendment}$ / V_{Soil}
CL	Soil with low content of compost	3 / 10
CM	Soil with medium content of compost	6 / 10
CH	Soil with high content of compost	9 / 10
BL	Soil with low content of biochar	3 / 10
BM	Soil with medium content of biochar	6 / 10
BH	Soil with high content of biochar	9 / 10
CBL	Soil with low content of compost and biochar	(1.5 + 1.5) / 10
CBM	Soil with medium content of compost and biochar	(3 + 3) / 10
CBH	Soil with high content of compost and biochar	(4.5 + 4.5) / 10

5.1.5. Plants

The plants were provided by the gardening company Buresinnova S.A. (Mercabarna Flor, Sant Boi de Llobregat). Three different showy species were chosen for aesthetic purposes, leaning on Mediterranean species: *Salvia officinalis*, *Melissa officinalis* and *Ruta graveolens*.

Although seeds or seedlings would have been more suitable for the experiment to avoid the influence of the soil already present in the pot, grown plants were chosen so they could be visible for the inauguration of City Station. Therefore, only the initial situation is evaluated in the present project. Changes in the plants due to the effect of the amendments are expected to be observed in the long term taking in account the project started in autumn, a season when plants do not undergo major changes.

5.1.6. Plot

A plot of approximately 100 m^2 was placed in City Station. The space was divided in areas of 1 square meter, and 5 plants were planted in each fraction drawing crosses, to represent the symbol of Natalie Jeremijenko's Environmental Health Clinic. To distribute the amendments to the plot, a random pattern would have been more suitable to avoid as much as possible environmental factors to affect the plot unevenly. Despite this, it was preferable to choose a more systematic distribution as the plot was meant to be plain to observers by showing differences in plant growth from one side to another. Therefore, amendment proportions were increased from right to left side, with three areas of untreated soils considered as controls, as shown in figure 2:

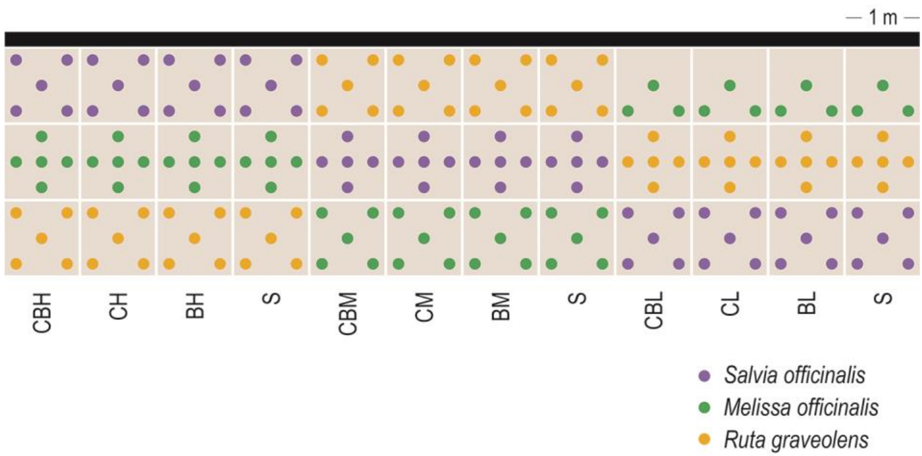

Figure 2. Distribution of the plants and treatments in the plot.

5.1.7. Planting

The application of amendment was local. For each spot where a plant had to be placed, an area of 20 x 20 cm was dug -as much as the root was expected to grow- and filled with the corresponding mixture before placing the plant (figure 3).

Figure 3. Planting of the plot.

5.1.8. Irrigation

Irrigation was provided by the gardening company Buresinnova S.A. (Mercabarna Flor, Sant Boi de Llobregat). Automatic irrigation was chosen to make sure the amount of water was the same for each plant. The plot was scarcely watered to provide demanding conditions for the plants and, thus, to make more evident the possible effect of the amendment in the retention of water.

5. 2. CHARACTERIZATION OF MATERIALS AND MIXTURES

5.2.1. Preparation of the samples

A previous treatment was done for all the materials and mixtures. The samples were passed through a 2 mm sieve. This size is a compromise established for the analysis of soil parameters, as the sample remains representative of the soil and ensures a suitable homogeneity for most analyses. Both size fractions were weighted to establish the percentage of the sample that remained below and above 2 mm. Once sieved, 10 g of each were ground to use in the analyses that required very low amount of sample.

5.2.2. Soil particle size

The particle size of the soil was determined from 20 g of the sample below 2 mm. The texture is only referred to the mineral matter, so we added 40 mL of H_2O_2 20 vol to eliminate the OM. Three days later, we added 40 mL of sodium hexametaphosphate, which acts as a dispersant by preventing the formation of aggregates, and stirred it for a whole night. After that, we poured the sample on a test tube of 1 L with two sieves above, one of 200 µm to contain the coarse sand and the other of 50 µm for the fine sand, and we separated the fractions that remained in the sieves. We made up the solution to the mark with deionized water, stirred and took an aliquot of 25 mL at 20 cm of depth for the silt. The size of the particles is correlated to the descent speed, which depends on the temperature. Therefore, considering the temperature of the water, the two remaining aliquots of 25 mL were taken after 5 minutes and 10 seconds at 10 cm of depth for the fine slime, and after 8 hours and 6 minutes at 10 cm of depth for the clay. We poured the aliquots into beakers and put them in the oven at 105 ºC until constant weight. The proportions of sand, silt and clay extracted from the aliquots were used to determine the type of soil.

5.2.3. Bulk density and humidity

Bulk density and humidity were determined for samples taken *in situ* in the plot of City Station. A cylindrical graduated tube was driven into the soil and a sample of known volume was extracted. The samples were hermetically closed and weighted once in the lab to determine the fresh weight. They were dried in the oven at 105 ºC until constant weight to determine the dry weight. Bulk density and humidity were calculated as follows:

$$\text{Bulk density}\ (g/mL) = \frac{\text{dry weight (g)}}{\text{volume (mL)}}$$

$$\text{Humidity}\ (\%) = \frac{\text{fresh weight (g) - dry weight (g)}}{\text{dry weight(g)}} \cdot 100$$

5.2.4. pH

The pH of the samples was determined with 10 g of the fraction below 2 mm, adding 25 mL of water and shaking for 5 minutes. After leaving to stand for 30 minutes it was slightly shaken and the pH was measured using a pH meter.

5.2.5. Water holding capacity

The WHC was determined from the fraction below 2 mm following the set up method (Appendix 1). The purpose was to set up a simple method applicable at home to determine WHC and see if it showed reliable differences between the samples. Therefore, we used this method to characterize the samples.

For the determination of the WHC, a bottle of 33 cL was cut in half. The upper part was put upside down, some cotton was placed in the neck of it and it was filled up with the sample, as shown in figure 4:

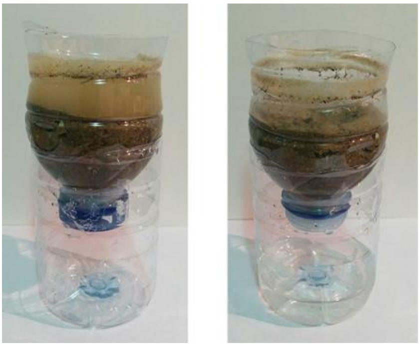

Figure 4. Assembly of the set up for the determination of WHC, filled with water (left) and after the drainage (right).

The upper part was weighted, and the dry weight of the sample was calculated by subtracting the weight of the bottle and the cotton from the value obtained. Then it was filled with water and left for 24 hours. After that, the bottle top was removed and the water was left to drain for 48 hours. The cotton was carefully removed, the bottle top was put again and the upper part of the bottle was weighted (the wet weight was calculated by subtracting the weight of the bottle). The WHC was calculated as follows:

$$\text{WHC (\%)} = \frac{\text{wet weight (g) - dry weight (g)}}{\text{dry weight (g)}} \cdot 100$$

5.2.6. Elementary analysis

The total carbon (TC), total nitrogen (TN) and total hydrogen (TH) were analysed at Scientific and Technological Centers of the University of Barcelona using an elemental organic analyser Thermo EA 1108 (Thermo Scientific, Milan, Italy) working in standard conditions recommended by the supplier of the instrument (helium flow at 120 ml/min, combustion furnace at 1000 ºC, chromatographic column oven at 60 ºC, oxygen loop 10 ml at 100 kPa).

5.2.7. Carbonate content

The carbonate content was determined by the Bernard calcimeter method. 1 g of each ground sample (weighed with precision of tenths of milligram) was put in a beaker, which was introduced in vertical position in an erlenmeyer with 25 mL of HCl 6 M. The erlenmeyer was then plugged to the calcimeter, and the level of the manometer liquid was adjusted to zero. It was then stirred so that the reaction could take place ($CaCO_3 + 2\ HCl \rightarrow CaCl_2 + CO_2 + H_2O$). The generated volume of CO_2 was measured in the graduated column. The carbonate of the sample was calculated from the volume of CO_2 with a calibration curve, by taking different amounts of $CaCO_3$.

The inorganic carbon was calculated from the carbonate by conversion factors, and the organic carbon was calculated by subtracting the inorganic carbon from the TC.

5.2.8. Organic matter content

The loss on ignition analysis was used as an indicative of the OM contained in the samples. 2 g of each sample were put in the oven at 105 ºC until constant weight (dry weight). The dry samples were put in the furnace at 450 ºC for 20 hours and weighed again (ash weight). The OM was calculated as follows:

$$\text{OM}\ (\%) = \frac{\text{dry weight (g)} - \text{ash weight (g)}}{\text{ash weight (g)}} \cdot 100$$

5.3. PLANT MEASUREMENTS

Some measurements of the plant were carried out to establish the starting situation of the field experiment and, by comparison with subsequent measurements, to study the effect of the soil quality in plant growth. Measurements included the leaf area index (LAI) and the green area (GA).

5.3.1. Leaf area index

The LAI is a dimensionless parameter that defines the area of leaves per ground surface area. It was determined for each species by cutting a few leaves of a plant, weighing them and scanning them to know the area they occupied (A_i) by means of the *ImageJ* tool (ImageJ, 2017). The leaves were put in the oven at 80 ºC to determine their humidity, and referred to dry weight (w_i). Then, all the leaves of the plant were cut and weighed, and referred to dry weight (w_t). The total area occupied by the leaves (A_t) was deduced from the relation between both dry weights. The LAI was calculated as follows:

$$A_t\ (m^2) = A_i\ (m^2) \cdot \frac{w_t\ (g)}{w_i\ (g)}$$

$$\text{LAI} = \frac{\text{total area of the leaves } (m^2)}{\text{area of the pot } (m^2)}$$

5.3.2. Green area

The GA indicates the percentage of an area covered by leaves. It was determined from the plants in City Station. Photos of each area of 1 m^2 were taken and processed with the program *Fiji* (ImageJ, 2017), which removes the colour from all the pixels except the green ones (figure 5) and uses the percentage of green pixels to determine the percentage of each square meter covered by leaves. The value obtained was divided by the number of plants contained in each square meter, and the average value of GA for each species was determined.

Figure 5. Original images (above). Images processed with the program *Fiji* (below).

6. EFFECT OF BIOCHAR AND COMPOST AS AMENDMENTS

6.1. CHARACTERIZATION OF THE MATERIALS

The particle size of the soil showed 90 % sand, 5 % silt and 5 % clay. According to the texture triangle, it was classified as a sandy soil.

As most of the determinations for the mixtures were done with only the fraction below 2 mm of the samples, the materials were characterized differentiating the fractions below and above 2 mm. This serves to check if this fraction is representative and makes a good approach to the plot in City Station. As shown in figure 6, the sieving showed clear differences in the particle size for soil (S), compost (C) and biochar (B). Whereas for S and C more than 50 % of the sample passed through the 2 mm sieve, B showed a much bigger particle size.

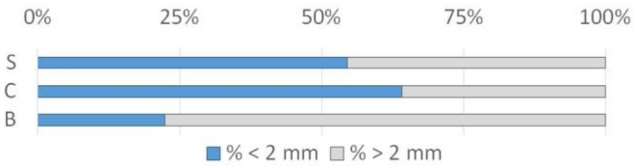

Figure 6. Percentages below and above 2 mm for each material.

Both fractions were characterized following the methods described in section 5. The values obtained (table 2) are alike for all the determinations. Their similar composition leads us to establish that the fraction below 2 mm is representative of the whole sample in terms of composition. However, the particle size might have an influence in parameters related to the behaviour of the materials e.g. acid neutralization capacity and CEC, as they depend on the surface area.

The elementary analysis showed little amount of carbon for the soil. Both amendments showed significantly higher levels, mainly proceeding from organic sources. The OM was also higher for the amendments. The ratio OM : organic C was not calculated for the soil because of its low content in carbon. The higher ratio for compost than for biochar is due to the nature of the materials: the lack of oxygen during the production of biochar makes it a material richer in carbon than compost. In spite of this, both amendments can act as a carbon sink when added to the soil.

Table 2. Values of TC, TN, TH, inorganic C, organic C, OM, and ratio OM : organic C for the fractions below and above 2 mm of the materials.

Parameter	S		C		B	
	< 2 mm	> 2 mm	< 2 mm	> 2 mm	< 2 mm	> 2 mm
TC (%) [a]	0.21	0.18	22.7	24.8	70.2	74.0
TN (%) [a]	<0.1	<0.1	1.98	1.81	0.61	0.42
TH (%) [a]	0.24	0.19	3.01	3.13	2.46	2.55
Inorganic C (%) [b]	0.1	0.1	1.2	1.3	0.5	0.8
Organic C (%)	0.1	0.1	21.4	23.5	69.8	73.2
OM (%) [c]	1.48	0.51	43.5	48.4	82.7	86.6
OM : organic C	-	-	2.0	2.1	1.2	1.2

[a] RSD < 0.4 %; [b] RSD < 0.2 %; [c] RSD < 0.6 %

WHC and pH were only determined for the fraction below 2 mm of the materials (table 3). WHC was significantly higher for both amendments than for the soil, having biochar a higher value than compost. This implies that both amendments can contribute to raise the WHC of the soil, and therefore to have more water available for the plants. The three materials showed high values of pH. Biochar had the highest value, while for compost it was lower than for the soil.

Table 3. Values of WHC and pH for the fraction below 2 mm of the materials.

Sample	WHC (%) [a]	pH [b]
S	24.0	8.81
C	131	7.95
B	193	9.57

[a] RSD < 3 %; [b] RSD < 1.2 %

6.2. ESTABLISHMENT OF THE PERCENTAGES OF AMENDMENT

Some of the determinations of the mixtures were done from the fraction below 2 mm. As the sieving showed important differences in the particle size of the materials, we had to establish the percentage of amendment that remained in this fraction for each mixture (figure 7). The proportions obtained in the sieving showed a lack of reproducibility. Although these differences were a limitation to carry out the determinations in the lab, they might not be a problem in City Station.

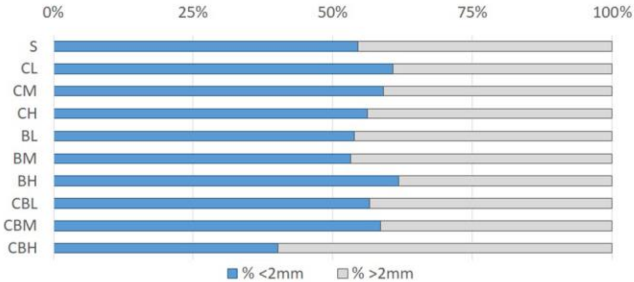

Figure 7. Percentages below and above 2 mm for each mixture.

We used the values obtained in the elementary analysis to determine the percentage of amendment in the fraction below 2 mm of the mixtures containing only one type of amendment, that is, for all the samples except CBL, CBM and CBH (table 4). A significant difference from mixtures with biochar to mixtures with compost can be observed, because most of the biochar cannot pass through the 2 mm sieve. The percentages calculated from TC may be more reliable than TN and TH, as the values are higher and imply a minor error.

Table 4. Percentage of amendment in the fraction below 2 mm of each mixture. Values deduced from the TC, TN and TH.

		CL	CM	CH	BL	BM	BH
Percentage of amendment deduced from:	TC	12 %	36 %	49 %	2.9 %	6.6 %	9.7 %
	TN	12 %	35 %	47 %	3.2 %	6.5 %	11 %
	TH	10 %	32 %	45 %	3.1 %	8.1 %	13 %

6.3. EFFECT OF THE ADDITION OF AMENDMENTS

The effect of the amendments in bulk density and humidity was studied for the field experiment in City Station (figure 8). Bulk density was clearly lowered when applying amendment in higher proportions. This means that the addition of both amendments enhances the root aeration and makes it easier for the plant to penetrate the soil. This can enable plant to better growth in urban soils that are too compacted. The humidity was determined after 48 h of abundant irrigation. It also showed a drastic change by the effect of the amendments. In this case the increase was more accentuated for compost than for biochar. Thus, we could deduce that the presence of compost in the soil would maintain moisture levels for longer, keeping favourable conditions to sustain plant growth.

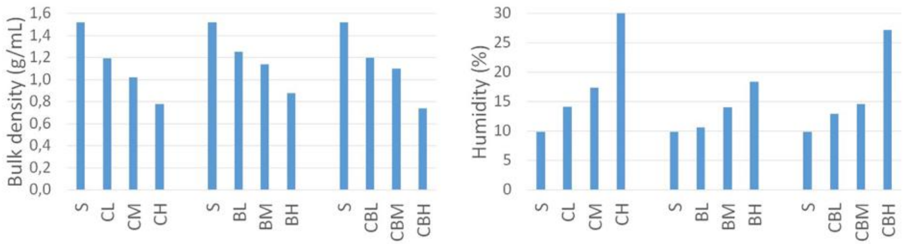

Figure 8. Values of bulk density and humidity for the samples in City Station.

The changes in pH and WHC caused by the amendments were determined in the lab (figure 9). The two different amendments affected the pH of the soil in opposite ways. Compost lowered the pH, which resulted in a positive effect considering the high pH of the soil itself. In contrast, biochar slightly increased it, although it caused a minor variation. The WHC was increased when higher proportions of amendment were applied, which showed the reliability of the set up method.

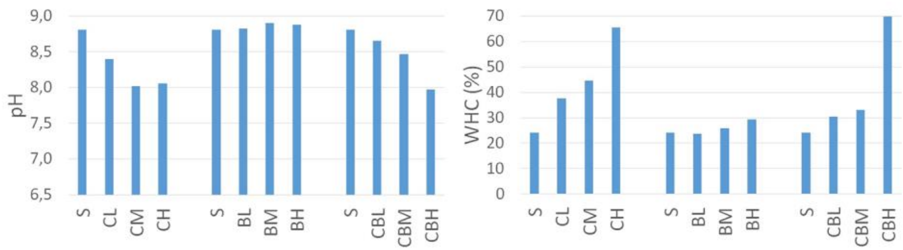

Figure 9. Values of pH and WHC for the fractions below 2 mm.

Although the humidity was determined from the whole samples and the WHC was determined from the fraction below 2 mm, both parameters showed a good correlation (R^2 = 0.87), as shown in figure 10. The relation between both parameters shows that in this case the fraction below 2 mm is representative of the whole sample. The increase in WHC was related to the OM provided by the amendments. Soils with a high percentage of OM have an increased availability of water for the plants, and this is one of the reasons for their enhanced ability to sustain plant growth. Both parameters were correlated (R^2 = 0.96). The fact that the correlation does not pass through zero is due to the presence of other phases, e.g. clays, that can contribute to the retention of water.

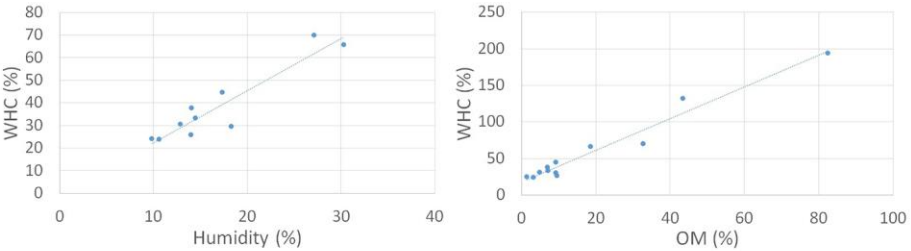

Figure 10. Correlation between WHC and humidity (left). Correlation between WHC and OM (right).

6.4. Plant measurements

The LAI and the GA were determined for *Salvia officinalis* (SO), *Melissa officinalis* (MO) and *Ruta graveolens* (RG). Whilst the GA was determined for all the plants in City Station, the determination of the LAI implied cutting a whole plant, so we could only do two replicates for each species. This caused a significant standard deviation. Both parameters were correlated (R^2 = 0.99) as shown in figure 11:

Species	LAI (m^2 of leaves / m^2 of soil)	GA (%)
SO	1960 (60)	3.5 (0.4)
MO	2600 (900)	4.5 (0.7)
RG	400 (200)	2.3 (0.3)

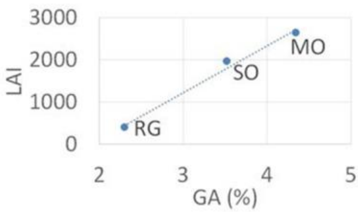

Figure 11. Mean values and standard deviation for LAI and GA (left). Correlation between both parameters (right).

7. CROSS-CUTTING ACTIVITIES

This project gave us the opportunity to take part in a series of activities, all of them in the framework of the exhibition of the CCCB.

7.1. ARTISTS TALK

For the inauguration of the exhibition, the CCCB organized an event where the artists involved in the exhibition exposed their point of view, their motivations and the impact they wanted to create in the audience. Although they were brought together by the climate crisis as a common motivation, they all had different ways to see it and they put emphasis in different aspects. The artists gave talks explaining the exhibition as they understood it and the sensations they wanted to convey to the spectators.

7.2. INAUGURATION OF CITY STATION

The inauguration of City Station took place on November 5th. A series of activities were organized for the occasion, which included the installation and planting of the plot for the field experiment, the planting of the vertical gardens (figure 12) and a scientific coffee break. The scientific coffee break was in charge of ISGlobal (Barcelona Institute for Global Health). It consisted in a participative talk related to environmental health and air pollution, where we shared our experiences and learned possible solutions to confront the problem at both individual and collective level.

Figure 12. Planting of the vertical gardens.

City Station is a space aiming at public participation. Therefore, all people present were invited to plant the vertical gardens. We used showy plants with a good root-leaf relation, to make sure they had enough space to grow roots and enough leaf area to cover most of the structure as they grew. After all the spots were filled, the structure was provided with automatic irrigation.

7.3. DOCTOR X RECIPES

Recipes take the form of laboratory protocols. Different audiences are considered, from primary schools to any person who visits the space. Therefore, recipes need to be understandable and easy to carry out. They are written in a plain language and the experiments that are proposed can be done with ordinary materials in an easy way. Even though, scientific rigor cannot be left aside.

One recipe was written in the context of this project: *Application of biochar to urban soils: improvement of soil quality* (Appendix 1). It proposes the determination of the WHC as described in section 5.2.5, to visualize the benefits of the use of amendments the soil.

7.4. MEDIATORS TRAINING

Mediators were people in charge of the City Station. They showed the space to visitors and carried out the recipes with them. As they had to know the recipe, we carried it out together to clear up doubts. We showed them all the material needed, how to proceed and what to explain to the visitors.

7.5. WORKSHOPS

Schools came to City Station as a scholar activity to do workshops aimed at introducing the students to a particular issue related to environmental health. Various schools did different workshops, according to the issue they were interested in. We ran one of the workshops, where the students came to learn about the application of biochar to urban soils to improve soil quality.

7.5.1. Preparation

The planned workshop was divided into two main parts. The first part consisted in an introduction to the soil quality issue and an explanation of biochar's environmental benefits. To do so we prepared some pictures to support the explanation and to make it easier to understand (figure 13). Pictures showed the carbon cycle and illustrated the benefits of biochar as an amendment. In the second part of the workshop, the students carried out the recipe *Application of biochar to urban soils: improvement of soil quality* to check the properties of biochar. As the recipe included the measurement of pH, we provided material of different pH -vinegar, soap, baking soda...- to explain the concept to the youngest students.

Figure 13. Pictures to support the explanation (Diputació de Girona, 2017).

7.5.2. Workshop

Only one session of the workshops was possible. The students were from the high school Juan Manuel Zafra. There were approximately 15 students, who were doing an optional subject of 4th ESO.

First of all, the carbon cycle was described with the support of the pictures to explain the capability of biochar for carbon capture. Then the situation of poor soils was raised, followed by an explanation of biochar's properties as an amendment.

In the experimental part of the workshop the recipe was carried out with the students. With environmental purposes, we asked them to bring their own plastic bottle to reuse it. Different students had different samples to use, to compare the results later in the class. We decided to use the same weight of each (100 g), so that students could compare the volume that samples occupied and therefore compare bulk densities. As the time was short and we were looking for immediate results, the samples were only left in contact with water for half an hour, and left to drain for half an hour more. pH was not measured from the drained water, because the water had been in contact with the sample for such a short time that the results would not have been reliable.

During breaks, the students could ask any question they had and we discussed it all together. They were very interested in the issue and we could clarify every doubt they had. The students were participative and asked many things, as they had not worked the subject before. After the participative talk we showed them how to calculate WHC from the weights obtained (figure 14), so that they could do it in class and compare the results obtained for each sample.

Figure 14. Calculation of WHC for the experimental part of the workshop.

Once in the classroom, the students continued to work with the subject and they did a presentation to the rest of the class, where they showed everything they had learned. The teacher found the activity very useful and profitable to the students, as it caught their attention and they showed interest.

8. CONCLUSIONS

The addition of compost and biochar to the soil showed changes in the assessed parameters:

- The bulk density of the soil was drastically lowered. This effect could have an important impact in urban soils that are too compacted.
- Humidity and water holding capacity were increased, showing the capacity of the amendments to retain water. This effect was related to a higher organic matter content.
- The addition of biochar did not cause major variations in the pH of the soil, whilst compost lowered it. The effect on the pH might be better observed in acidic soils, where the high pH of biochar can result in a positive effect for vegetation growth.
- Whereas the addition of compost showed a larger increase in water holding capacity, the bigger particle size and higher pH of biochar might be beneficial in compacted and acidic soils. Therefore, the mixing of both amendments could lead to better effects in the soil.
- The assessed parameters showed that higher proportions of amendment lead to more optimal conditions to sustain plant growth.
- The initial status of the plants was set up as the starting point of the field experiment. Green area and leaf area index were satisfactorily correlated.

The workshops were implemented successfully:

- The set up method to determine water holding capacity showed reliable differences between samples and resulted easy to carry out by the audience.
- The implementation of the recipes had a positive response in the public.
- The workshops were useful for the students. They showed interest during the session and acquired knowledge about biochar.

9. FURTHER WORK

This project has established a basis for the approach to more ambitious objectives. We propose a series of work to give it continuity.

Soil parameters and plant growth need to be further studied:

- Further determinations should be done to characterize the materials and mixtures. Whereas the already studied parameters are mostly referred to the composition of the samples, parameters related to the material behaviour, e.g. acid neutralisation capacity and cation exchange capacity, should also be assessed.
- Soil parameters should be determined again for the mixtures in City Station after a few months to test the stability of the amendments.
- Plant growth needs to be determined in a few months. As the starting point is already set, the final state of the plants will serve to evaluate the effect of the amendments in plant growth.
- Root growth should also be studied by means of rhizotrons.

Additional sessions of the workshops should be done:

- The recipe *Application of biochar to urban soils: improvement of soil quality* should be put in practice with different audiences to see how they respond.
- A recipe related to the improvement of plant growth could also be implemented.

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11. ACRONYMS

CEC: Cation Exchange Capacity

GA: Green Area

LAI: Leaf Area Index

OM: Organic Matter

TC: Total Carbon

TH: Total Hydrogen

TN: Total Nitrogen

WHC: Water Holding Capacity

APPENDICES

APPENDIX 1: DOCTOR X RECIPE

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Aplicació de biochar als sòls urbans: millora de la qualitat del sòl

Context

Una bona qualitat dels sòls urbans a les ciutats és imprescindible per aconseguir zones verdes frondoses que permetin millorar la salut de la població a través de la renovació de l'aire i del seu paper terapèutic per a les persones. Els sòls urbans, degut a que sovint han estat afectats per activitats industrials, solen estar compactats, per la qual cosa tenen poca capacitat de retenir aigua i nutrients necessaris per a un creixement adequat de les plantes i, fins i tot, poden contenir substàncies contaminants com poden ser els metalls pesants. Aquesta situació és especialment acusada al Poblenou, antiga zona fabril, però també s'estén a altres zones de la ciutat.

Objectius

L'addició de biochar, producte d'origen orgànic reciclat a partir de la transformació de biomassa (per exemple, residus de poda), es proposa com esmena del sòl per a la millora de la qualitat d'aquest. L'objectiu d'aquest protocol és comprovar la millora de la qualitat del sòl urbà pel que fa a la retenció d'aigua i nutrients, a l'augment del pH i aconseguir així un major creixement de les plantes en les zones verdes de la ciutat.

Competències científiques

- Aprendre el concepte d'esmena i de biochar
- Aprendre el concepte de retenció hídrica o capacitat de camp.
- Aprendre el concepte de pH per comparació entre els valors de pH obtinguts en l'experiment i el d'altres substàncies que es poden trobar a casa (vinagre, bicarbonat, lleixiu, sabó, etc.).
- Comparar la retenció hídrica i el pH de sòl sense esmenar i esmenat amb diferents dosis de biochar.

Materials

Per dur a terme aquest experiment necessitarem els següents materials:

- Sòl urbà
- Biochar (també es podrien emprar residus compostats)
- Ampolles d'aigua de 33 cL de plàstic transparent
- Cotó fluix

- Paper film o d'alumini
- Aigua
- Paper indicador per a la mesura del pH
- Balança de cuina

Passes a seguir

Per tal de demostrar la millora de la qualitat del sòl quan s'esmena amb biochar, es proposa el següent experiment que es pot realitzar a casa o a l'escola:

1. Escolliu un sòl urbà.
2. Prepareu mescles de sòl amb quantitats creixents d'esmena de biochar, entre un 2 i un 5 % d'esmena sobre el pes total de la barreja sòl-biochar, per tal de realitzar experiments en paral·lel.
3. Talleu les ampolles d'aigua per la meitat.
4. Al coll de cada ampolla, amb el tap posat, col·loqueu cotó fluix que permeti passar l'aigua, però no el sòl.
5. Dins d'aquesta part de l'ampolla, amb el tap a la part inferior, empleneu amb sòl (o mescla sòl-biochar) fins que ocupi la meitat del volum. Peseu i anoteu el pes.
6. Recolzeu la part de l'ampolla amb el sòl, sempre amb el tap a la part inferior, dins l'altra part de l'ampolla.
7. Aneu addicionant aigua a poc a poc i mullant tota la superfície fins que el volum d'aigua superi aproximadament 1 cm el nivell del sòl (o mescla sòl-biochar).
8. Tapeu la part superior amb paper film o d'alumini per evitar que s'evapori l'aigua i deixeu que el sòl estigui en contacte amb l'aigua durant 24 hores.
9. Retireu el tap i deixeu que l'aigua s'escorri durant 48 hores.
10. Retireu el cotó fluix moll per tal de no considerar el pes d'aigua que ha retingut i peseu novament la part de l'ampolla que conté el sòl (o la mescla sòl-biochar), ara humit. La diferència de pes observada respecte el pes inicial permet calcular el tant per cent d'aigua retingut pel sòl (o per la mescla sòl-biochar).
11. Mesureu el pH de l'aigua que ha passat a través del cotó fluix a l'altra part del recipient. Per fer-ho, submergiu el paper indicador a l'aigua i compareu el color obtingut amb els que es mostren a l'escala per tal d'obtenir el valor de pH.
12. Compareu els resultats, tant per la retenció hídrica com pel pH, obtinguts per al sòl i per les mescles sòl-biochar.

Obtenció de dades

Per deixar constància de la teva contribució a la millora global del sòl urbà, pots introduir les dades obtingudes en aquest experiment al web www.estaciociutat.barcelona o entregar el formulari que se't facilita als mediadors de l'Estació Ciutat.