E3S Web of Conferences **350**, 01005 (2022) https://doi.org/10.1051/e3sconf/202235001005
EREGCE 2022

Biochar Amendment in the Green Roof Substrate Improve Air Quality

Yishu Hu[2] and *Haoming* Chen[1,2,*]

[1]School of Environmental and Biological Engineering, Nanjing University of Science and Technology, Nanjing 210094, China.
[2]College of Resources and Environmental Sciences, Nanjing Agricultural University, Nanjing, Jiangsu 210095, China.

Abstract. In this paper, biochar was added to the green roof in order to study the effect of biochar amendment on improving the air quality. Simulation experiments showed that biochar treatments can reduce the concentration of CO_2 by 7.3-28.8%, CO by 10.6-20.7%, SO_2 by 9.8-21.6%, and NO_2 by 2.1-11.5% in the micro-environment. Outdoor monitoring experiments showed that biochar can reduce 24.0-46.6% of PM2.5, 3.7-23.3% of PM1.0, and 17.3-38.4% of PM10. In addition, the high temperature is the main factor affecting the adsorption of small particles. Structural equation analysis showed that biochar mainly absorbed the particulate matters and harmful gases by reducing the surface temperature, increasing the humidity and promoting the plants growth.

1 Introduction

Seven million people die every year due to air pollution [1]. Urban air pollutants are mainly dust come from solid waste combustion, automobile exhaust emissions and tire friction. PM2.5 and PM10 have become the hot issues of the pollutants. Green roofs can absorb and filter particles and dust in the air. At the same time, they can absorb various harmful gases such as CO, NO and SO_2 in the air. However, because of the harsh roof environment, the green roof combined with soil and plants is often difficult to achieve the expected ecological benefits. In order to further improve air quality and repair air pollution by green roofs, biochar was used as a soil amendment in this study. Biochar has many merits such as rich pore structure, so biochar has the function of adsorbing air pollution. The raw materials of biochar come from solid organic waste. Therefore, the production and use of biochar can also contribute to solid waste resource utilization. Adding biochar into the green roof substrate is a potential method to purify the air pollution.

2 Materials and Methods

2.1 Materials

Sludge biochar (SB) and urban natural soil (Pukou District, Nanjing, 5-10cm above the ground) were mixed for roof greening research. SB with the treatment of pyrolysis and dehydration at 600°C is provided by Mississippi International Water (China) Co., Ltd. (Hangzhou, Zhejiang Province). The heavy metal indicators of biochar meet the national standards (AQSIQ and SAC, 2009) and can be used for roof greening. *Sedum lineare Thunb* was planted on the green roof, which seeds were purchased from the Jiangsu Academy of Agricultural Sciences.

2.2 Methods

2.2.1 Experimental Method

There are five treatments in the experiment, with different ratio of biochar and soil (CK, 5%SB, 10%SB, 15%SB, 20%SB). Each treatment has 3 repetitions. The test plants were traditional roof plants: *Sedum lineare Thunb.* The average biomass of plants during the monitoring period was CK (9.15±1.2 g/plant), 5%SB (11.93±0.9 g/plant), 10%SB (13.21±1.1 g/plant), 15% SB (15.65±0.8 g/plant) and 20% SB (15.37±1.2 g/plant). Air purification experiment (simulation): uses the simulation box shown in Figure 1. The hole above the analog box is sealed with tape, and to prevent gas loss the gas measuring port is plugged with a cotton plug when not detecting. The polluted air (the flue gas produced by the burning of 1g mixture of fallen leaves, dried branches and straw) is filled into the simulation box (Fig.1). The pollutant concentration of simulated gas is shown in Table 1. The simulation time of the experiment is from 10 am to 1 pm in the unobstructed outdoor space, so that the test can ensure that the plants can be illuminated fully by the sun and can carry out effective photosynthesis.

Environmental monitoring experiment (outdoor, Fig.2): A portable air quality detector (LB-S06, Lianyungang Lanbao Electronic Technology Co., Ltd., Fig.3A) is used for monitoring. The monitoring indicators are PM2.5, PM1.0, PM10, temperature, humidity and wind speed. The instrument is placed in the center of each treatment sample plot, 5cm high from the

* Corresponding author: chenhaoming89@hotmail.com

ground. The environmental climate during monitoring is shown in Table 2.

Table 1. Pollutant concentration of simulated gas

	PM2.5 μg/m³	PM1.0 μg/m³	PM10 μg/m³	CO_2 mg/m³	CO mg/m³	SO_2 mg/m³	NO_2 mg/m³
Pollutant concentration	356±87	178±85	381±68	21051±566	1277±37	15±7	92±21

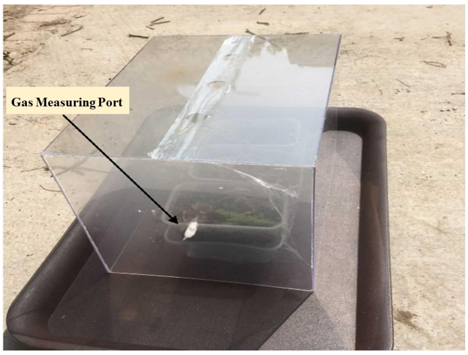


Fig. 1. Simulation box of roof greening air purification test

Fig. 2. Roof greening air purification test

Table 2. Environmental climate table

Date	Maximum temperature	Minimum temperature	Weather	Wind direction	Wind force
2016/12/8	16 ℃	5 ℃	Partly Sunny	Southwest	3-4
2016/12/19	16 ℃	9 ℃	Partly Rainy	Northeast	1-2
2017/1/2	14 ℃	5 ℃	Cloudy	North	3-4

2.2.2 Sample collection and analysis method

The air condition was detected by a portable gas detector (CD4(B) multi-parameter gas detector, Beijing Zhuoan Hengrui Technology Co., Ltd., Fig 3B). To prevent the loss of polluted gas, the air should be detected at 1 h, 2 h, 3 h after the injection of the polluted gas and be measured in the simulation box with an air intake of 500 ml every 30 minutes. The conversion is carried out according to the following formula: Mass concentration (mg/m³) = Substance molecular weight (M) ÷ 22.4× Volume concentration (ppm).

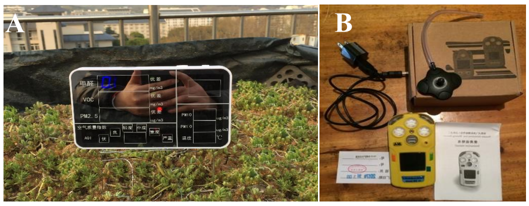
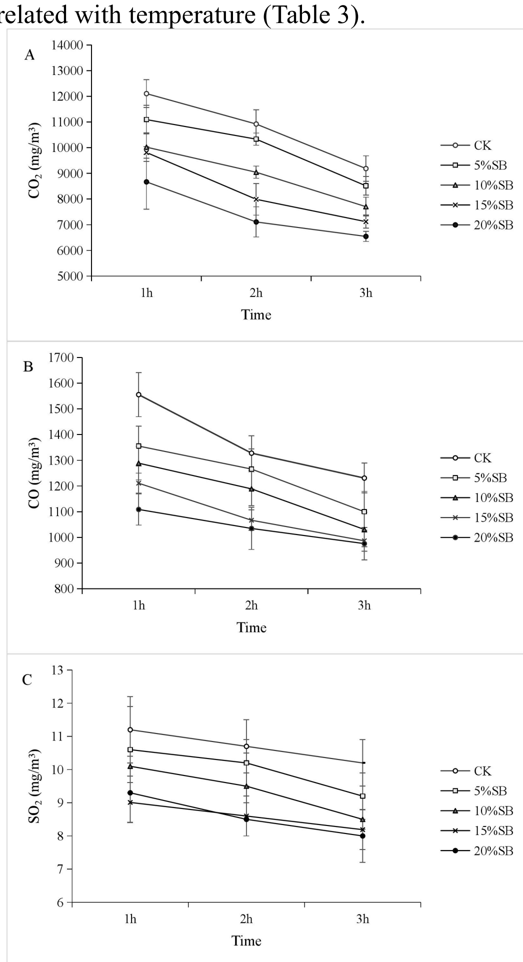


Fig. 3. Air quality tester

3 Results

3.1 The effect of air purification on green roof by biochar amendment

The simulation test results show that the green roof with biochar treatment has a stronger effect on air pollution elimination, which can reduce CO_2 by 7.3-28.8%, CO by 10.6-20.7%, SO_2 by 9.8-21.6% and 2.1 -11.5% of NO_2 (Fig 4). With the increase of time, the air purification capacity of the green roof with biochar treatments is always better than those without biochar. The decrease rate of CO concentration slows down with time, but the decrease rate of NO_2 concentration increases with time. The correlation shows that the concentration of the four gases is negatively correlated with water, but positively correlated with temperature (Table 3).



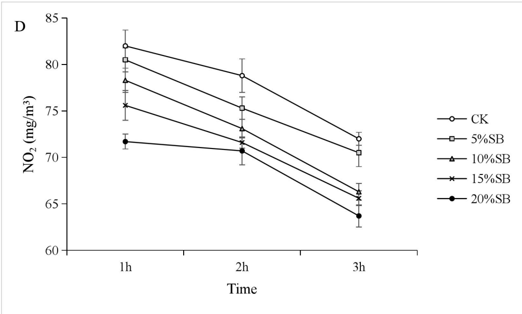


Fig. 4. Changes in the influence of roof greening on air pollution
(A) CO_2, (B) CO, (C) SO_2, (D) NO_2.

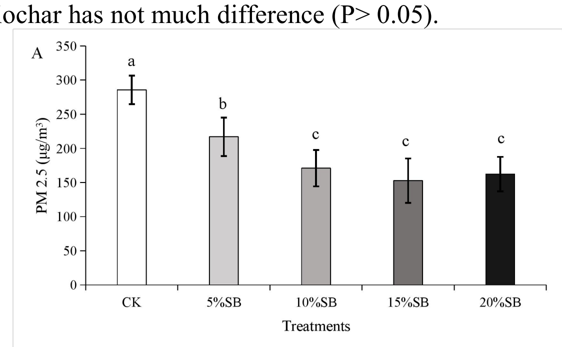
Table 3. Correlation analysis of substrate temperature and moisture and pollution gas in roof greening

		CO_2	**CO**	**SO_2**	**NO_2**	**Temperature**	**Humidity**
CO_2	Pearson's r	1.00	0.961**	0.873**	0.50	0.894**	-0.930**
	P Value		0.00	0.00	0.06	0.00	0.00
CO	Pearson's r	0.961**	1.00	0.921**	0.47	0.858**	-0.929**
	P Value	0.00		0.00	0.08	0.00	0.00
SO_2	Pearson's r	0.873**	0.921**	1.00	0.32	0.743**	-0.882**
	P Value	0.00	0.00		0.25	0.00	0.00
NO_2	Pearson's r	0.50	0.47	0.32	1.00	0.606*	-0.566
	P Value	0.06	0.08	0.25		0.02	0.04
Temperature	Pearson's r	0.894**	0.858**	0.743**	0.606*	1.00	-0.805**
	P Value	0.00	0.00	0.00	0.02		0.00
Humidity	Pearson's r	-0.930**	-0.929**	-0.882**	-0.566	-0.805**	1.00
	P Value	0.00	0.00	0.00	0.04	0.00	

* The correlation is significant at 0.05
** The correlation is significant at 0.01, n = 15

3.2 The effect of particle adsorption on green roof by biochar amendment

The test results show that the particle adsorption capacity of the green roof with biochar treatments is stronger than those without biochar, which can reduce PM2.5 by 24.0-46.6%, PM1.0 by 3.7-23.3%, PM10 by 17.3-38.4% and 13.6-50.9% AQI, respectively. (Fig 5). The analysis of variance showed that the purification efficiency of PM2.5 and PM10 treated by the green roof with 10-20% biochar has not much difference (P> 0.05).



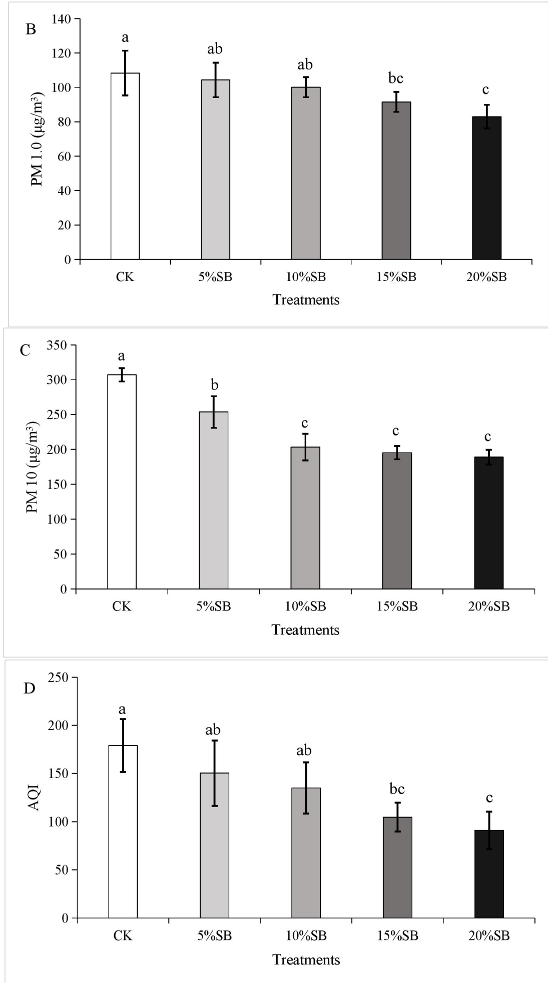


Fig. 5. Effect of biochar on purification of particulate pollutants by roof greening
(A) PM2.5, (B) PM1.0, (C) PM10, (D) AQI.

3.3 The effect of air quality on green roof by environmental factors

Outdoor test results show that the air quality level of roof greening has very strong correlation with temperature (R^2 = 0.637-0.757), humidity (R^2 = 0.516-0.684), wind speed (R^2 = 0.579-0.684) and botany (R^2 = 0.534-0.709) (Table 4). The higher the particle pollutant index is, the more serious the pollution will be. Therefore, the test results show that the purification effect of roof greening on particle is negatively correlated with temperature, and positively correlated with humidity, wind speed and botany (Table 4). Through structural equation analysis, it is found that biochar has no significant effect on PM2.5 and other particles (path coefficient = 0.11). It mainly enhances the adsorption of particles by influencing the near-ground temperature, humidity and vegetation, indirectly (Fig 6).

Table 4. Correlation analysis of particulate matter near the roof and roof environment in roof greening

		PM2.5	**PM1.0**	**PM10**	**AQI**	**Temperature**	**Humidity**	**Wind Speed**	**Botany**
PM2.5	Pearson's r	1	0.635*	0.860**	0.714**	0.801**	-0.827**	-0.812**	-0.761**

	P Value		0.011	0	0.003	0	0	0	0.001
PM1.0	Pearson's r	0.635*	1	0.639*	0.870**	0.809**	-0.809**	-0.809**	-0.731**
	P Value	0.011		0.01	0	0	0	0	0.002
PM10	Pearson's r	0.860**	0.639*	1	0.721**	0.870**	-0.807**	-0.830**	-0.842**
	P Value	0	0.01		0.002	0	0	0	0
AQI	Pearson's r	0.714**	0.870**	0.721**	1	0.798**	-0.718**	-0.761**	-0.804**
	P Value	0.003	0	0.002		0	0	0	0
Temperature	Pearson's r	0.801**	0.809**	0.870**	0.798**	1	-0.988**	-0.901**	-0.937**
	P Value	0	0	0	0		0	0	0
Humidity	Pearson's r	-0.827**	-0.809**	-0.807**	-0.718**	-0.988**	1	0.769**	0.931**
	P Value	0	0	0	0	0		0	0
Wind Speed	Pearson's r	-0.812**	-0.809**	-0.830**	-0.761**	-0.901**	0.769**	1	0.837**
	P Value	0	0	0	0	0	0		0
Botany	Pearson's r	-0.761**	-0.731**	-0.842**	-0.804**	-0.937**	0.931**	0.837**	1
	P Value	0.001	0.002	0	0	0	0	0	

* The correlation is significant at 0.05,

** The correlation is significant at 0.01, n = 15

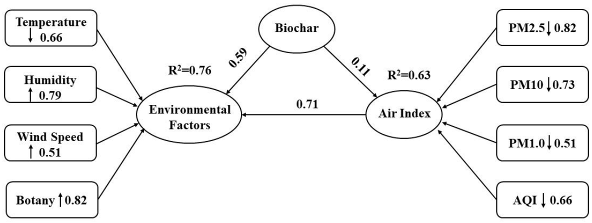


Fig. 6. Structure equation diagram of the effect of biochar on air particulate matter

4 Discussion

There are two main ways for biochar amendment to improve air quality. Firstly, it can help to reduce the emission of polluting gases in the roof matrix. Secondly, it can promote the growth of plants and strengthen the absorption of polluted gases by plants.

The results of this experiment show that the air pollution index of roof greening treated with biochar is lower than those without biochar. And the purification effect of CO_2 and SO_2 is the best (Fig 3). The reason why biochar can effectively reduce the emission of CO_2 and CO is that it can strengthen the photosynthesis of plants, which enhance plants to absorb a large amount of CO_2 and CO. In our previous study, it has been proved that biochar can improve plant growth [2]. And it can also regulate the soil temperature and moisture [3] so that the carbon sequestration capacity of the soil will be improved. Studies have shown that soil temperature is one of the factors that affect the improvement of CO_2 by green roofs [4]. Changes in soil temperature may also change the growth and community structure of microorganisms, thereby affecting soil CO_2 emissions. The water content of the substrate in this experiment is negatively correlated with the concentration of CO_2. This may be because substrate water can lead to the formation of an anaerobic environment, thus inhibiting the oxidation activity of microorganisms and reducing CO_2 emissions [5]. The results also show that temperature has a significant correlation with humidity (R^2 = 0.648). Because of the complexity of the roof environment, temperature changes are often affected by substrate humidity. Temperature and humidity will have a synergistic effect on CO_2 emissions in soil and the air [6].

The reason why the addition of biochar can reduce the concentration of NO_2 is that biochar increases soil porosity. Especially in the low moisture condition, it can increase the oxygen content of the soil and inhibit the anaerobic denitrification process. Biochar can also improve soil pH, thus reducing NO_2 emissions from soil [7]. In addition, biochar provides protection and nutrients for beneficial microorganisms related to the nitrogen cycle, and promotes their reproduction [8].

The addition of biochar significantly reduces the concentration of SO_2 in the air, since biochar increases the plants and leaf area. In addition, because biochar increases the water content of the substrate, the evaporation effect of the substrate is enhanced. So that SO_2 can be dissolved in the water vapor of the air, and then absorbed by the plant leaves and the soil.

Comparing the purification of three types of particles, it is found that the adsorption of green roof with biochar on PM2.5 and PM10 is stronger than that on PM1.0 (Fig 4). This phenomenon is due to the strong sunlight radiation on the roof, which rises the surface temperature of the substrate and causes dust pollution. In addition, the rise of hot air brings small particles higher, which intensifies the pollution of small particles in the roof environment. Besides, the results show that wind speed has a significant impact on PM2.5 in the roof air. The wind speed increases the settling rate, thereby improving the adsorption effect of plant leaves [9].

Plants have always been the main way for green roofs to purify the air due to the adsorption and transformation capacity. The results show that plants have a significant correlation with air quality (Table 4). Plant leaf morphology, leaf area, and leaf coverage can all affect the adsorption efficiency of particles. In addition, plants can also change the spatial pattern of pollutant on the roof by affecting air flow, increasing or decreasing the local pollutant concentrations [10]. Higher pollution concentration in the simulation box than that in the outdoor test is because the circulation limitation and the difficulty of pollutant diffusion [11].

In conclusion, biochar added in green roofs can not only improve the air quality, but also further promote the ecological benefits, such as purifying air. Green roof with biochar treatment can reduce the concentration of CO_2, CO, SO_2 and NO_2 in micro-environment. In addition, the results show that biochar can improve the adsorption of particles in the air by green roofs. Biochar can also improve the roof micro-environment by adjusting the soil environment and promoting plant growth.

References

1. B. Kuehn, WHO: More Than 7 Million Air Pollution Deaths Each Year. JAMA: the journal of the American Medical Association, **311**, 1486 (2014)
2. H.M. Chen, J.Y. Ma, X.J. Wang, P. Xu, S. Zheng and Y. Zhao, Effects of biochar and sludge on carbon storage of urban green roofs. Forests **9(7)**, 413 (2018)
3. J. Lehmann, Bio-energy in the black. Frontiers in Ecology and the Environment **5(7)**, 381-387 (2007)
4. X. Li, H. Fu, D. Guo, X. Li and C. Wan, Partitioning soil respiration and assessing the carbon balance in a Setaria italica (L.) Beauv. Cropland on the Loess Plateau, Northern China. Soil Biology and Biochemistry **42**, 337-346 (2010)
5. B. Liang, J. Lehmann, S. Sohi, J. Thies, B. O'Neill, L. Trujillo, J. Gaunt, D. Solomon, J. Grossman, E. Neves and F. Luizão, Black carbon affects the cycling of non-black carbon in soil. Organic Geochemistry. 206-213 (2010)
6. B. Gao, X. Ju, F. Su, Q. Meng, O. Oenema, P. Christie, X. Chen and F. Zhang Nitrous oxide and methane emissions from optimized and alternative cereal cropping systems on the North China Plain: A two-year field study. Science of The Total Environment **472**, 112–124 (2014).
7. Y. Wu, G. Xu, Y. Lu and H. Shao Effects of biochar amendment on soil physical and chemical properties. Adv. Earth Sci. **29**, 68-77 (2014).
8. S. Steinbeiss, G. Gleixner and M. Antonietti, Effect of biochar amendment on soil carbon balance and soil microbial activity. Soil Biology and Biochemistry **41**, 1301-1310 (2009).
9. P. Freer-Smith, A. El-Khatib and G. Taylor Capture of Particulate Pollution by Trees: A Comparison of Species Typical of Semi-Arid Areas (Ficus Nitida and Eucalyptus Globulus) with European and North American Species. Water, Air, and Soil Pollution **155**, 173-187 (2004)
10. Z. Tong, T. Whitlow, P. MacRae, A. Landers and Y. Harada, Quantifying the effect of vegetation on near-road air quality using brief campaigns. Environmental Pollution **201**, 141-149 (2015)
11. S.D. Sabatino, R. Buccolieri, G. Pappaccogli and L. Leo, The effects of trees on micrometeorology in a real street canyon: consequences for local air quality. International Journal of Environment and Pollution **58**, 100 (2015).