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Environmental Effects of Biomass Carbon Modified Bioretention Pond Fill Layer in Sponge City Gardens

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Abstract: With the expansion of urban green areas, the resulting increase in green waste has become the second-largest solid waste in the city. Green waste contains a lot of minerals and the recycling of its resources has become the urgent task of urban green development. Biochar technology is more in line with the concept of green environmental protection in Sponge City. In order to improve the utilization rate of green waste and rainwater resources, the study proposes to apply this technology to the waste disposal of urban gardens. Firstly, the soil quality of the city and the disposal methods of garden waste were investigated and analyzed. Then the waste was pyrolyzed and carbonized as material and the soil improvement indoor test and sponge soil outdoor test were carried out. At the same time, the pollutant interception and water retention function of biochar materials were tested. The results showed that the interception flow rates of the three experimental groups treated with biochar technology were 29.37, 33.14 and 31.98 L, respectively, which were significantly higher than those of the untreated group. The average total nitrogen removal rate of the three treatment groups was above 36% and the removal effect was significantly higher than that of the control group. Sponge soil has good infiltration coefficient and water retention performance and the water retention capacity can be increased by 30%. During rainfall, the water content of soil treated with sponge soil was 8.6~9.9% higher than that without sponge soil treatment. The concentration of suspended particulate matter in soil liquid under the treatment of sponge soil is significantly lower than that in the untreated original soil. This shows that the use of biochar technology can enhance the soil modification capacity in sponge cities and promote the resource recycling of urban waste.

Keywords: Sponge Cities, Biomass Carbon, Bioretention Ponds, Waste, Environment

Introduction

The rapid development of global urbanization leads to a large number of land resources being occupied and consumed. At the same time, the urban expansion is accompanied by large-scale road hardening, which intensifies and reduces the urban permeable area (Sut-Lohmann *et al.*, 2022). However, the traditional rainwater management methods, such as the reconstruction of rainwater pipes, have alleviated the problem of waterlogging in the short term, but in fact caused a lot of waste of rainwater resources. In contrast, the concept of sponge city is to use the natural foundation of the city as a water regulation system, by enhancing the permeability and retention of water, so that rainwater can be stored when it is abundant and released when it is needed (Chorol and Gupta, 2023). To some extent, this approach improves the natural capacity of cities to cope with water management. However, at present, the absorptive function of urban soil is often damaged by human factors, such as trampling, mechanical compaction and other activities and even the loss of water permeability. In addition, the construction of urban gardens has also brought challenges in the disposal of garden waste. As a potential renewable resource, garden waste needs to be paid enough attention to its resource reuse (Yang *et al.*, 2022). Like solar energy, wind energy and other renewable energy, through scientific planning and effective management, the recycling and utilization of garden waste is sustainable, helping to reduce the burden of municipal treatment, while providing a new resource guarantee for urban ecological construction. Therefore, many scholars at home and abroad have also launched in-depth discussions on the recycling of garden waste.

Science Publications

Mishra and Yadav (2022). used in-vessel composting to treat garden wastes at the community level by selecting suitable containers and determining the physicochemical and biological parameters such as temperature, humidity, aeration, etc. required for composting and got better results (Mishra and Yadav, 2022). Ipek and Ajna found that garden waste can be added to the soil as organic fertilizer after proper treatment. Organic fertilizers provide nutrients, improve soil structure and increase soil water retention and retention. This is important for soil quality enhancement and plant growth in forest debris (Šipek and Šajna, 2020). Gupta and Mahajani studied the kinetics of pyrolysis of garden waste using a fixed-bed laboratory reactor with biomass pellets to analyze the gases produced during pyrolysis. The study showed that the method is good for observing the kinetics of pyrolysis of garden waste (Gupta and Mahajani, 2020). At the same time, some scholars have proposed the use of biochar to improve urban soil. Biomass carbon is a carbonaceous organic compound obtained by solid-liquid-gas decomposition of biomass under high temperature and oxygen-limited conditions and biomass carbonization has been widely studied and practiced in the agricultural field (Shukla and Jain, 2022). Li *et al.* (2022) used biocarbon as a medium for the adsorption of ammonia from simulated wastewater and subsequently as a nitrogen-releasing agent for growing rice under nitrogen-deficient conditions. The experiment showed that biochar can help to improve the spatial balance of "mismatched" nitrogen resources (Li *et al*., 2022). Hasan used different mulch materials and biochar to increase soil temperature and determine its effect on lettuce yield.

The study found that the application of biochar increased yields by 218% over conventional solarisation and about 300% over the control (Öz, 2023). Ouedraogo *et al.* (2023) used biomass-derived biochar to remove pollutants such as suspended solids, heavy metals, nutrients and organic pollutants from highway stormwater runoff. The study showed the vast potential of biochar for pollutant removal and its use in treating highway stormwater runoff (Ouedraogo *et al*., 2023). Among them, garden biomass carbon has the advantages of a large specific surface area, strong adsorption capacity and water-holding capacity, which is in line with the concept of sponge city construction. Combining biomass carbon with garden soil can effectively solve the problems of poor permeability and serious pollution of urban soil and can give full play to the water permeability and water retention of the natural subsurface of urban soil (Sheeja and Harilal, 2022). A comprehensive study shows that garden waste is rich in organic matter and is a special biomass resource in human economic activities. However, the current methods of disposing of these wastes, such as composting and incineration for power generation, are not environmentally friendly and the recycling rate of resources is low. The technology of converting biomass into carbon, the products made of garden biochar have a high specific surface area, adsorption capacity and water retention, which is consistent with the development concept of sponge city. However, in the current research on the use of biochar in sponge city facilities, the selection of materials is too simple and the specific relationship between the allocation mode and proportion, its hydrological benefit and pollutant treatment efficiency is not clear. Therefore, the use of biochar to promote sponge city construction needs to rely on more research support. Therefore, the study proposes to take a sponge city garden as a research object, to explore the main problems and limiting factors of the soil of the garden green space in the region, to carbonize the garden biomass waste and to analyze the impacts on the quality of the garden soil and the soil functions related to sponge cities through this biomass carbon. The study aims to link waste treatment with urban ecosystem building to achieve a closed loop and overall improvement of urban ecology. The study is divided into a total of 4 parts. In Part 1 of the article, the background and significance of urban garden waste treatment and sponge cities are mainly introduced. Part 2 is the content of the experimental methodology of biomass carbon.

Materials and Methods

Environmental Effects of Biomass Carbon Modified Bioretention Cell Packing Layer Experimental Materials and Methods

Experimental Materials

Under the high-temperature condition of 750°C, the biomass material will undergo thermal decomposition, carbonization and other processes and finally form the biomass carbon material with a porous structure. Therefore, garden biomass carbon at 750°Cwas selected as the basic material of a spongy body. Then greening waste compost after secondary crushing, urban waterworks sludge, the above materials by wind dry crushing are over the 2 mm vibrating sieve. Among them, the garden biomass carbon and greening waste organic compost were provided by Shenzhen Bolin environmental protection Co. Ltd and the experiment was applied to Taiwan grass with the same growth. Garden biomass carbon is a kind of carbon material obtained by treating garden waste under low oxygen or no oxygen conditions, usually in the range of 400-700°C. It has a highly porous structure, which can improve soil ventilation and water retention. Compared with other organic matter, biomass carbon is more stable, can provide the growth environment of soil microorganisms and improves soil fertility. Green waste compost is an organic fertilizer obtained from garden waste through a biodegradation process (usually under micro-oxygen or aerobic conditions), after a period of accumulation and fermentation treatment. It contains a lot of organic matter, such as nitrogen, phosphorus, potassium and so on. Helps to increase the number and diversity of beneficial microorganisms in the soil and improve soil health.

The instruments used in the experiment included a soil temperature sensor (S-TMB-M006), Soil moisture sensor (S-SMC-M005), portable digital conductance meter (DDB-12), salt sensor (FJA-10), leaf chlorophyll analyzer, plastic baffle, water bucket, etc. The soil temperature sensor (S-TMB-M006) is generally able to accurately measure soil temperature in the range of 40-100°C and has a high measurement accuracy, such as ±0.5°C. The soil moisture sensor (S-SMC-M005) is able to measure the convolutional ratio of soil water content, usually in the range of 0-100%, with an accuracy of ±3% (Chen *et al.*, 2023; Choudhuri *et al.*, 2023). The materials required for the experimental procedure were a small peristaltic pump, shower, several buckets, measuring cylinders and beakers. The bioretention cell setup is shown in Fig. 1.

The main body of the bioretention cell unit in Fig. 1 is an earth column with an inner diameter of 15 cm and a height of 100 cm. From top to bottom, there is a 15 cm high aquifer layer, a 10 cm high layer of sand and gravel with a diameter of less than 3, a 50 cm filler layer and a 25 cm high layer of pebbles. Table 1 shows the raw materials and their basic properties of the filler layer of the bioretention pond.

The unit weight, organic carbon, available Phosphorus (P), available Potassium (K), soil PH (PH), Cation Exchange Capacity (CEC), soil Conductivity (EC), total nitrogen (TN) and Total Phosphorus (TP) contained in the feedstock of the filling layer of the biological retention pond are introduced in Table 1.

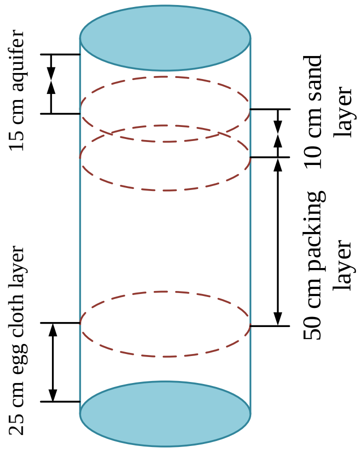


Fig. 1: Biological retention tank device

Experimental Methods

The study set up four groups of control experiments based on the traditional bioretention tank structure with an improved packing layer. The traditional bioretention tank packing layer was used as the control group, i.e., the CK group. Different proportions of garden biomass carbon were used, replacing part of the urban soil with sludge carbon, replacing wood chips with garden waste secondary compost and adding appropriate amounts of iron oxides to each of the two treatments, setting up two treatments, A1, A2 and A3. The specific configuration method is shown in the following table. The proportion of raw materials formulated for the filler layer of the ecological retention pond is shown in Table 2.

Table 1: Raw materials and basic properties of the filler layer of a biological retention pond

Basic property	Sludge carbon	Garden charcoal	Garden soil	Planting soil	Sawdust.
Unit weight (g-cm)$^{-3}$	0.45±0.06	0.33±0.03	1.33±0.11	1.11±0.08	0.12±0.01
Organic carbon (g-kg)$^{-1}$	64.39±3.22	607.89±26.11	6.06±1.64	21.18±0.30	242.15±16.26
Rapidly available P (mg-kg)$^{-1}$	/	/	12.35±1.26	41.66±2.87	/
Rapidly available K (g-kg)$^{-1}$	6.59±0.55	15.63±3.18	0.11±0.01	0.28±0.04	/
PH (H$_2$O)	8.24±0.03	10.09±0.37	7.59±0.20	7.11±0.34	6.44±0.23
CEC (cmol-kg)$^{-1}$	10.48±1.05	16.22±2.09	21.34±4.31	48.21±6.16	/
EC (uS-cm)$^{-1}$	1352.01±25.45	844.01±13.26	38.25±4.20	71.61±5.24	/
TN (g-kg)$^{-1}$	1.52±0.04	12.19±1.01	0.36±0.01	1.35±0.10	2.23±0.50
TP (mg-kg)$^{-1}$	69.42±5.79	4.31±0.26	/	/	36.14±4.53

Table 2: Raw material preparation ratio of the filling layer of an ecological retention pond

Raw material	CK (%)	A1 (%)	A2 (%)	A3 (%)
Local soil	80	30	30	30
Clay	10	10	10	10
Garden biochar	/	10	10	20
Sludge carbon	/	40	40	30
Iron oxide	/	03	03	03
Garden compost	/	07	07	07
Sawdust	10	/	/	/

The experiment was divided into two phases, the first is the domestication phase, the rainwater and tap water collected in the previous period were mixed into the filler layer, stirred evenly and then dried for 3-5 days to ensure that the filler was consistent with the natural rainfall conditions. Next is the formal test phase, namely the ecological retention soil column system, runoff coefficient of 0.9, catchment area and retention area ratio of 10:1. Test to take the intermittent water intake mode, the design of rainfall for 50 mm/24 h, once into the water volume of 8L, the control of a constant flow rate of 550 m/min. Simulation of natural rainfall wet and dry alternation, the sampling time of 5 d, until the soil column occurred serious clogging or run-off Water quality is basically the same as the original water quality. All leachate was collected during each rainfall event, the time of inflow and outflow was recorded and the total volume of samples collected was measured. The samples were sent to the laboratory immediately after sampling, stored at 4°C and tested within 48 h. The data to be recorded during the modeling of the runoff treatment included the date of the experiment and remarks, the time of water intake, the time of water exudation when leachate flowed out, the total amount of water collected in two times at t1 and t2, respectively, the number of experiments, the total amount of water injected and the total amount of water collected at the end. Table 3 shows the concentration and determination of pollutants in the simulated surface runoff.

Add Biomass Carbon Configuration Sponge Soil and Field Test Experimental Materials and Methods

Experimental Materials

The sponge soil configuration materials selected for the experiment are garden biomass carbon prepared at 800°C, garden waste compost after secondary crushing, urban water field sludge and yellow clay, the above materials are air-dried and crushed through a 2 mm vibrating screen. The experimental site of the garden biomass carbonization plant is located in Guangzhou. The workshop covers an area of about 1200 m^2 and has a height of 10 m. The air circulation inside the workshop is very good and is usually kept at about 20°C. The operating procedures and necessary safety measures for the equipment work, as well as various warning signs, are posted in the workshop. At the same time, its power and water supply systems are stable, fire prevention facilities are complete and it is equipped with a surveillance system that enables real-time monitoring of the operating conditions of the plant and equipment. Taiwan grass was selected as the ground cover plant. Other test materials include data sensors, plastic water baffles, water collection buckets, rain gauges and guide pipes. The basic physical and chemical properties of the test materials are shown in Table 4.

Table 3: Concentration and measurement methods of simulated surface runoff pollutants

Runoff pollutant	Simulate stormwater runoff concentration	Surface runoff limit	Required medicine	Determination method	Reference method
COD(mg·L^{-1})	150	40	$KHC_8H_4O_4$	Potassium Dichromate standard method	GBT 22597-2008 determination of chemical oxygen demand in reclaimed water
NH^+_4(mg·L^{-1})	4.0	2.0	NH_4Cl	Nessler	HJ 535-2009 water quality determination of ammonia nitrogen
NO_3^-(mg·L^{-1})	4.0	/	KNO_3	Ultraviolet spectrophotometry	HJ-T 346-2007 water quality determination of nitrate nitrogen
TP(mg·L^{-1})	3.0	0.2	KH_2PO_4	Ammonium Molybdate spectrophotometry	GB 11893-1989 water quality-determination of total phosphorus
TN(mg·L^{-1})	14.0	4.0	$C_3H_7NO_2$	TOC instrument measurement	TOC meter

Table 4: Physicochemical properties of spongy soil improvement base materials

Physical and chemical properties	Garden biochar	Garden organic compost	Waterworks sludge
Water content	44.09±0.39	35.05±3.89	32.09±0.59
Unit weight	0.29±0.01	0.50±0.01	0.77±0.01
pH (H_2O)	10.01±1.21	8.30±0.40	6.71±0.34
SOM	607.8±10.55	82.91±3.61	415.0±25.1
TN	12.01±0.88	1.18±0.21	21.05±4.32
TP	4.31±0.33	1.15±0.07	9.11±2.0

Table 5: Sampling plots

Lot 1		Lot 1	
Area/m^2	4×5	Area/m^2	4×5
Ploughing depth/cm	30	Ploughing depth /cm	30
Add sponge soil composition (1:1:3)	Garden biochar, secondary compost scraps, sludge soil Additive-free	Add sponge soil composition	
Weight/t	3	Weight/t	3
Laying thickness/cm	25	Laying thickness/cm	25

Experimental Methods

The experimental site was located in a park in Guangzhou, China. This modified site was originally a retained plot of mountain soil excavation with an inclination angle of about 20° and was originally a manila lawn. The experiment selected plots with the same ground cover environment and terrain, the basic characteristics of which are shown in Table 5. In the two plots, the corresponding species of Taiwan grass block sod with the same growth was laid.

In Table 5, each plot was deeply plowed for 30 cm and then man-made sponge soil was added to its surface. The sponge soil was made of garden biomass carbon, secondary compost crushed material, water plant sludge and yellow clay, which were mixed thoroughly in the mass ratio of 1:1:3. Its total weight is 3 t and the final cover layer is 25 cm thick. The other piece is also plowed 30 cm deep on its surface and the top layer is covered with the same soil as the on-site soil excavated from the surrounding grassland and the cover layer is 25 cm thick. The Taiwan grass block turf with the same growth is laid on the two plots correspondingly. In order to better collect surface runoff water without affecting the test results, PP boards were used as water barriers all around the experimental area and water catchment tanks were set up at the bottom of the slopes, which are usually used to record the amount of water in the water guide pipe and the water meter, as well as water catchment buckets buried in the soil and connected to the water guide pipe and rain gauges placed in the open space. A total of three natural rainfall events were recorded from the beginning of November 2021 to the end of December 2021 once the experimental laying was completed.

During the implementation of this rainfall study, the entire rainfall process was carefully divided into three stages: Early, middle and late, with the purpose of capturing and analyzing the differences in the impact of different rainfall stages on surface runoff characteristics and water quality. The precipitation process is further divided into two main periods: No runoff period and a significant runoff period, which is helpful in understanding the specific impact of rainfall on surface runoff. After the rainfall reaches the stage of significant runoff production, a strict sampling procedure is adopted to collect and analyze runoff water samples. A litre water sample is taken from the collection bucket every 20 min for analysis and three independent samples are taken at the same point in time to ensure repeatability and accuracy of the data.

Measurement Methods

Soil bulk weight was determined using a ring knife with a volume of 100 cm^3. Soil pH and EC were measured using a water-soil ratio of 10:1 by shaking the soil with a pH meter with a conductivity meter. SOM was determined by titration with concentrated H_2 SO4-K2 Cr_2O7 external heating-FeSO4 and TN was determined by titration with semi-micro Kjeldahl-H_2 SO_4 Effective phosphorus in soil was extracted by molybdenum blue colorimetric method using formic acid as solvent. Effective potassium was determined by the NH_4 Ac leaching-flame photometric method. Sensors buried at a depth of 30 cm were used to measure parameters such as ground temperature, mass water content and EC in the field. The equipment was an S-TMB-M006 temperature sensor and an S-SMC-M005 soil moisture sensor (Fig. 2) (Lin *et al*., 2023; Ahn *et al*., 2020).

The quality of runoff water was measured using the following methods. TSS values were determined according to the national standard weighing method. TN, TP, COD and NO3--N were measured using a portable Hash-hash water quality analyzer. The dissolver and spectrophotometer used were manufactured by Hash Corporation of the U.S.A., models DRB200 and DR900 (Zhong *et al*., 2021) respectively (Fig. 3).

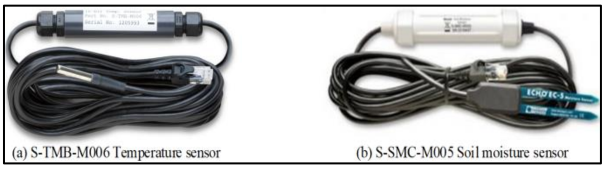

(a) S-TMB-M006 Temperature sensor
(b) S-SMC-M005 Soil moisture sensor

Fig. 2: Sensor device

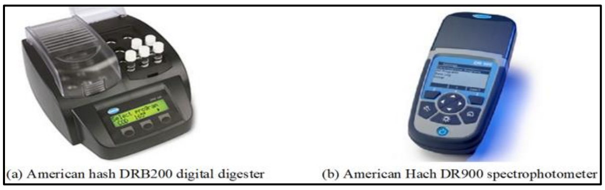

(a) American hash DRB200 digital digester
(b) American Hach DR900 spectrophotometer

Fig. 3: Digestion instrument and spectrophotometer

The biomass and enzyme activities of Taiwan grass were measured by the following methods. In each treatment, 10 strains were randomly selected, cleaned and dried with absorbent paper and then weighed directly with a sensitivity of 0.01. The kits used for the assay of Malondialdehyde (MDA) and Taiwan grass Superoxide Dismutase (SOD) were provided by the Nanjing Institute of Built Biology and both enzymes were pretreated in the same way (Gonçalves *et al*., 2019). That is, 0.5 g of plant tissue was accurately weighed out and then 4 times the volume of homogenization medium, i.e., 2 mL of phosphate buffer with pH 7.0, was mechanically homogenized in an ice-water bath to make a 20% homogenized slurry. The supernatant was centrifuged at a speed of 3000-4500 r/min for 10 min and removed for measurement (Wang *et al*., 2022). To measure mda, follow the equipped kit, cover the centrifuge tube, prick a small hole in the lid with a needle, mix well with a vortex and water bath at 95°C (or boil it in a pot with the lid open for 40 min, fish it out and cool it with tap water and centrifuge it at 3500-4000 r/min for 10 min (longer centrifugation times below 3000 r/min to allow for thorough sedimentation) (Tevzadze *et al*., 2022). Absorbance was measured in each tube at 532 nm with an optical diameter of 1 cm and zeroed with distilled water. *Mda* in plant tissue homogenates was calculated as shown in Eq. (1) (Al_Saadi *et al*., 2021; Bimonte *et al*., 2021):

$$MDA = \frac{A_{OD} - B_{OD}}{C_{OD} - D_{OD}} \times E \times F \tag{1}$$

In Eq. (1), indicates the sample *OD* value. Stands for control *OD* value. Indicates the *OD* value of the standard sample. Indicates the *OD* value of the blank sample. Denotes the standard sample concentration, which is 10 nmoL/m. Represents the sample dilution (Tang *et al*., 2019). For the determination of *SOD*, the samples were mixed according to the equipped kit, following the standard procedure and the color was developed at 550 nm on a 1 cm diameter cuvette, zeroed with distilled water at 550 nm (Dhaliwal *et al*., 2020). Determination of *SOD* activity in plant tissue homogenates. Definition: The amount of *SOD* per gram of tissue at 50% *SOD* inhibition in 1 mL of reaction solution is one unit of *SOD* activity (U). The calculated expression of *SOD* activity is shown in Eq. (2) (Song *et al*., 2021; Mu *et al*., 2021):

$$SOD = \frac{B_{OD} - G_{OD}}{B_{OD}} \times \frac{50\% H}{I} \times J \tag{2}$$

In Eq. (2), represents the measured *OD* value. Represents the volume of reaction liquid (mL) and represents the sampling volume (mL). Represents the homogenate concentration (g/mL).

Experimental Analysis

Experimental Analysis of the Effect of Biomass Carbon Modified Bioretention Ponds

The experiments were conducted using Excel 2010 software for data processing and plotting, SPSS 23.0 software for one-way correlation and difference significance analysis and Duncan's method for significance test ($p<0.05$). A total of 13 water intake tests were conducted and the cumulative water intake was 104 L of simulated runoff water the effect of water retention and infiltration in the bioretention pond is shown in Fig. 4.

From Fig. 4(a), it can be seen that the average retention time after treatment in the CK group was significantly lower than in other treatment groups, which was 6.10 min. The average retention time in the A1, A2 and A3 treatment groups was 6.92, 6.83 and 7.19 min, respectively. The differences among these three groups were not significant. From Fig. 4(b), it can be seen that the water retention capacity of each treatment group varied significantly and was higher than that of the CK group. The intercepted flow rate of the A1, A2 and A3 treatment groups was 29.37 L, 33.14 L and 31.98 L, respectively. In conclusion, the experimental group supplemented with garden biochar had stronger water retention ability than the untreated CK group. Figure 5 shows the variation of pollutant leaching concentration of the four experimental groups of bioretention tank influent test.

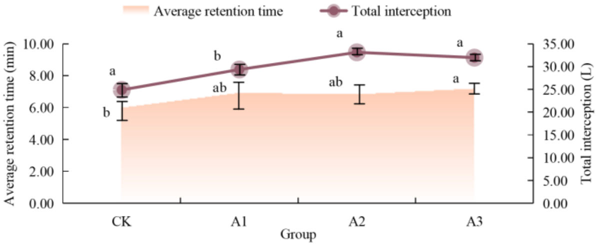


Fig. 4: Effects of water retention and infiltration in biological retention ponds

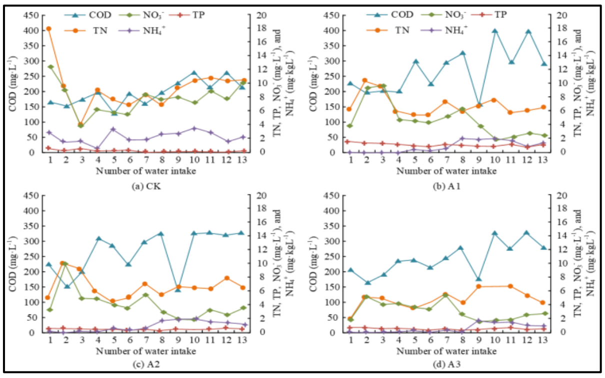


Fig. 5: Change of leaching concentration of pollutants in an influent test of a biological retention pond

As can be seen from Fig. 5, in 13 influent tests, the concentrations of COD, TN, TP, NH_4+ and NO_3 showed an obvious changing trend with the influent times. COD and NH_4+ show instability and their concentrations tend to rise with the increase of influent times. On the contrary, the concentrations of TN, NO_3-and TP showed a slow decreasing trend with the increase of influent times. The single COD leaching amount is over 100 mg-L-1, which is significantly higher than the standard limit of 40 mg-L-1 for surface flow production. In all groups, COD leaching in the CK group was generally lower than that in other treatment groups except the 9th test. The TP leaching rate in the CK group was significantly higher than that in the A1 and A2 treatment groups, while the TP leaching rate in the A3 treatment group was significantly lower than the other two groups. The leaching concentration of NO_3-in group CK first increased and then stabilized with the increase of influent times, while that in other treatment groups showed a downward trend, especially in group A3, where the leaching concentration of NO3-was always maintained at a low level. Although the concentration of NH_4+ increased with the number of influent times, the leaching concentration of NH_4+ in all treatment groups was lower than the surface runoff limit of 2 mg-L-1 and the leaching concentration of NH_4+ in the A3 treatment group was lower than that in other treatment groups. Figure 6 shows the pollutant removal and retention for the bioretention cell influent test.

As can be seen from Fig. 6, the single average leaching amount of COD for all four treatments was above 150 mg-L-1. Among them, the average leaching amount of the CK group was significantly lower than that of the A1, A2 and A3 groups. The average leaching amount of A1, A2 and A3 groups was more than 200 mg-L-1 and the difference between treatments was not significant. The average removal rate of CK reached about 26%, which was significantly lower than that of the A1, A2 and A3 groups. The average TN removal rate of the three treatment groups was over 36% and the TN removal rate of the A3 treatment group was 45%, which was significantly higher than that of the A1 and A2 treatment groups. The NO_3-removal rate of the CK and A1 treatment groups was negative and the CK removal rate was 71.2%, which was not much different from that of the A1, A2 and A3 treatment groups. The single-shot average NH_4+ removal rate of the CK and A3 groups was the lowest, with 34.8, 57.2 and 59.2%, respectively. 34.8 and 57.2%, respectively and the A1, A2 and A3 treatments were significantly higher than the removal effect of CK. The CK group had the highest removal efficiency for TP, while the A1, A2 and A3 treatment groups had significantly lower removal effects for TP than the CK group.

Add Biochar Carbon Configuration Sponge Soil Off-Site Experimental Analysis

The experiment takes "sponge city" as the research object, mixes garden biomass carbon, garden waste compost and other organic materials and configures the artificial soil with the sponge city's required subsurface. The experiment is intended to explore different rainfall intensities, artificial sponge soil water retention performance, infiltration performance and runoff pollutants intercepting capacity. Table 6 shows the statistical results of two heavy rainfall events in November 2021 captured.

Significant runoff was observed in the test untreated and sponge soil plots after both rainfall events. The untreated virgin soil plots produced runoff in the range of 12-14 min after rainfall. In contrast, the artificial sponge plots produced runoff for about 30 min, about 20 min later than the untreated plots. Figure 7 shows the variation of 30 cm soil mass water content during rainfall.

As can be seen from Fig. 7(a), the water absorption of the soil in the untreated raw soil was increasing in the first 10 min of precipitation. After 12-14 min, the saturated water content of the soil reached 25%, which was the period of flow production. However, under the action of sponge soil, the water content showed a tendency to rise first and then to saturate again at the end of precipitation. From Fig. 7(b), it can be seen that the moisture content of the topsoil increased by 8.6-9.9% during rainfall compared to untreated. This indicates that the sponge soil has a strong ability to absorb and retain precipitation and has an obvious flow-blocking effect on runoff. Figure 8 shows the concentration changes of TN and TP in runoff water samples from the experimental plots under rainfall.

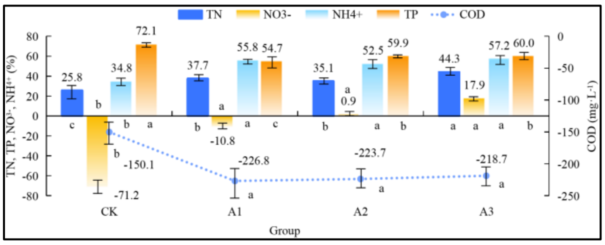
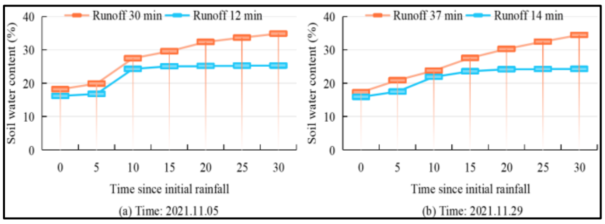


Fig. 6: Removal rate and retention of pollutants in the influent test of biological retention pond



(a) Time: 2021.11.05

(b) Time: 2021.11.29

Fig. 7: Changes of 30 cm soil mass water content under two rainfrains

Table 6: Rainfall results of sponge soil test treatment test site

			Runoff onset time ----------------------------	
Duration rainfall	Start-stop time	Rainfall/ mm	Untreated raw soil	Spongy soil
2021.11.05	9:30~11:00	36	9:40	10:00
2021.11.29	14:30~16:0029	14:50	15:20	

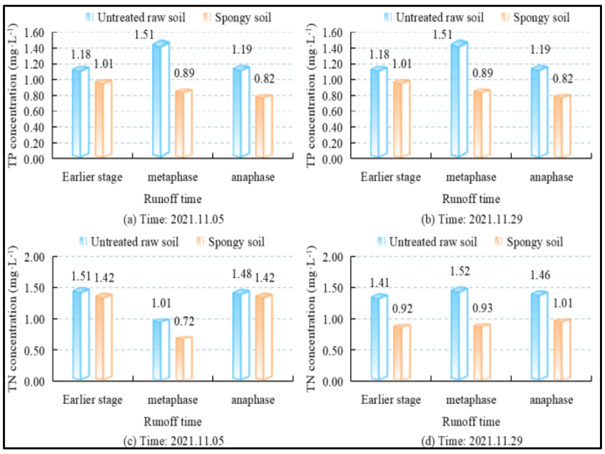


Fig. 8: TP and TN concentrations of runoff water samples during rainfall events

As can be seen in Figs. 8(a-b), there was no significant relationship between runoff water total phosphorus concentration and runoff yield time, but the difference between the two topsoil soil scenarios was highly significant. Total phosphorus in runoff from the sponge soil after both rainfall events was significantly lower than the untreated soil by more than 30%. From Figs. 8(c-d), it can be seen that after the rainfall on 5 November, the mid-term TN concentration of runoff water was the lowest. At the end of the period, the TN concentration returned to the level of the previous period, with no significant difference under the two treatments. However, after the rainfall on 29 November, the TN concentration of runoff water under the sponge soil treatment was significantly lower than that of the untreated original soil, both in the early, middle and late stages. Figure 9 shows the concentration changes of NO3- and NH_4+ in the runoff water samples of the experimental plots under rainfall.

As can be seen from Figs. 9(a-b), the NH_4+ concentrations of both treatments were the lowest at the end of the period after the rainfall on 5 November. The NH_4+ concentration of the sponge soil treatment was significantly smaller than that of the untreated soil before and during the middle of the runoff. However, after the rainfall on 29 November, the protection pattern was similar. From Fig. 9(c-d), it can be seen that the NO_3- concentration of runoff water did not change much with the time of runoff output. At the end of the runoff period, there was no significant difference between the two treatments. However, during runoff formation, the NO_3- concentration in the untreated raw soil exceeded 20% of the sponge soil treatment in all cases. Figure 10 shows the variation of COD and TSS concentrations in runoff water samples from the experimental plots under rainfall.

From Figs. 10(a-b), it can be seen that after rainfall on 5 November, the COD concentration of runoff water collected for three times under both treatments was significantly higher in untreated raw soil than in sponge soil. The same situation was observed for COD concentration in runoff water collected after rainfall on 29 November. From Figs. 10(c-d), it can be seen that the content of TSS gradually decreased with the flow production process after two rainfall events. The TSS content at the beginning of the runoff from the first rainfall was not significantly different between the two treatments, while there was no significant difference at the end of the runoff from the second rainfall.

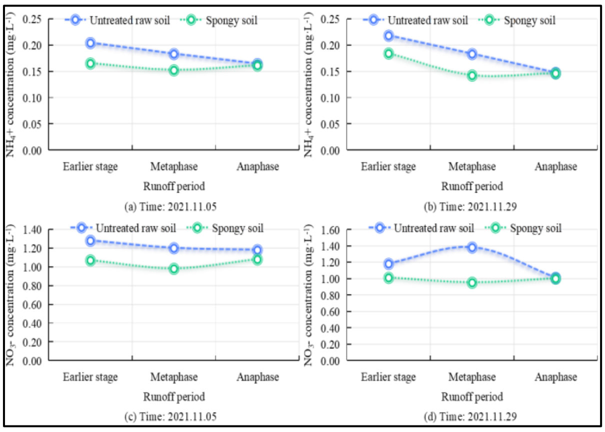


Fig. 9: NH_4^+ and NO_3^- concentrations of runoff water samples during rainfall events

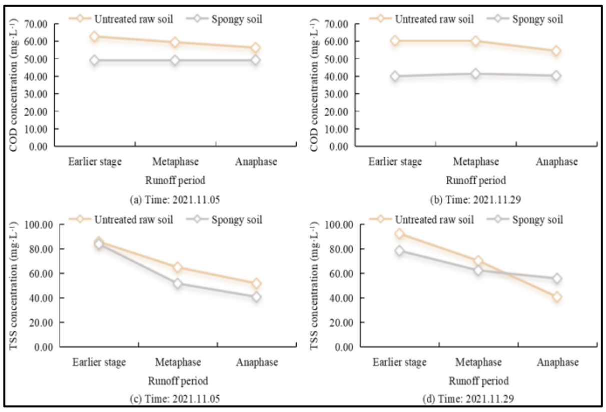


Fig. 10: COD and TSS concentrations of runoff water samples during rainfall events

Results

The experimental results showed that the treatment groups (A1, A2, A3) with garden biochar added to the biological retention tank had significant water retention capacity, and the interception flow rate was higher than that of the untreated CK group. At the same time, the treatment groups showed great differences in the leaching and removal effects of pollutants. The concentrations of COD and NH_4^+ increased with the increase of influent times, while the concentrations of TN, NO_3^- and TP decreased. The leaching concentrations of COD and NH_4^+ in the treatment group were generally higher than those in the CK group, but the NH_4^+ was lower than the surface runoff limit of 2 $mg{\cdot}L^{-1}$. The removal effects of TN and NO_3^- in the A3 treatment group were the best, reaching 45% respectively and significantly lower than those in other treatment groups. During heavy rainfall events, sponge soil plots significantly delayed the formation time of runoff, enhanced soil water absorption and water content, and effectively reduced the concentrations of total phosphorus, total nitrogen, NO_3^-, NH_4^+, COD and TSS in runoff water. Especially after the second rainfall, the indexes of various pollutants treated by sponge soil were significantly lower than those of untreated soil, indicating that sponge soil had a strong ability to block flow and remove pollutants under rainfall conditions. In conclusion, the application of biological retention pond and sponge soil has significantly improved the water retention and pollutant control effect of water body.

Discussion

The experimental results showed that the interceptions of the A1, A2 and A3 treatment groups were 29.37, 33.14 and 31.98 L, respectively and were higher than those of the CK group. This showed that the water-holding capacity of soil was effectively enhanced after the addition of biochar. The research method has a better effect on rainwater interception than the method in the literature (Ouedraogo *et al.,* 2023). The removal of pollutants was significantly different among the treatment groups, which showed a better rainwater interception effect than previous studies. In particular, the treatment efficiency of COD, TP and NO_3- is the most prominent, which is mainly reflected in the late stage of rainfall. This may be because as rain continues, soil moisture increases, reducing particulate matter in runoff. In the experiment, the plots subjected to charcoal application showed lower COD loss, which may be due to the use of Taiwan grass bark to reduce direct erosion of soil by rain and enhance soil water infiltration and retention. Because of its large specific surface area and rich oxygen-containing functional groups, biochar shows strong adsorbability to organic matter in water. In the case of heavy rainfall, the specially configured sponge soil significantly improved the reduction effect of suspended solids, COD, TN, TP and NO3- in runoff and the reduction range was between 15 and 50%, indicating the effectiveness of green belt in filtering and purifying pollutants. This is in common with the research of some scholars in literature (Li *et al.,* 2022). In addition, the study also indirectly showed that artificial sponge soil can effectively increase the biomass of green vegetation and promote the health of plants. This is consistent with the research results of various researchers in the literature (Öz, 2023).

Conclusion

To achieve the comprehensive improvement of closed circulation and urban ecology, the study took Guangzhou city as an example to deeply explore the main problems and limiting factors of urban garden green soil. A solution to improve the soil quality of the sponge city garden by carbonizing biomass waste was proposed. By adding biomass carbon into the soil, the experimental results showed that the improved soil had a significant increase in water infiltration and retention effect and the interception rate was significantly increased compared with the control group, the specific data were 29.37 in group A1, 33.14 L in group A2 and 31.98 L in group A3. The leaching concentration of NO_3^- in the soil supplemented with biomass carbon showed a decreasing trend, indicating the denitrification effect and the average removal rate of total nitrogen in the three treatment groups exceeded 36%. In terms of NH_4+ removal rate, except CK, other treatment groups also showed significant advantages. In the case of heavy rainfall, sponge soil can effectively slow down water flow and increase the water retention capacity by 30%. In addition, during rainfall, the water content of surface soil increases by 8.6-9.9% compared with that of untreated soil, which has higher rainwater absorption and retention capacity. The TSS concentration of treated surface runoff water also decreased significantly, reaching between 16 and 26%, indicating that sponge soil has a significant effect on improving urban runoff water quality. This study provides an effective strategy for the construction of an urban ecological closed loop and sponge city. However, the study did not delve into the classification of carbonization effects of different types of biomass. The experiment of "sponge soil" and "three-dimensional green substrate" only considered the influence of the initial growth of plants and the long-term effect is still unclear. Therefore, future research will focus on expanding the scale of garden biomass carbonization, optimizing system performance and improving the quality of carbonized products to support factory production. Further, explores the application of biochar in urban ecological construction, promotes the recycling of urban soil greening waste and realizes the ecological closed loop.

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Author's Contributions

Wen Cao: Methodology; written-original draft.
Beibei Zu: Investigation; written and edited.

Ethics

The experimental design has been approved by the university's ethics review committee. All participants were fully aware of the purpose of the experiment, volunteered to participate and signed informed consent.

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