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Analysis on the Rainwater Retention Capability of Mulches in Urban Green Space

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ABSTRACT

'Sponge city construction' has led to higher requirements for rainwater absorption in urban green space. When the rainwater absorption capacity of typical underlying layers in urban green space, i.e., plants and soil, is limited, mulch can often make up for the deficiency in the rainwater absorption capacity of the green space. This study focuses on four types of mulch: loose pine cone scales, broadleaf oak bark, coconut shells, and sawdust, and conducts rainwater harvesting to measure their rainwater retention efficiencies. The results are as follows: in terms of mass, coconut shells weighed 3.87 times their original mass after absorption; in terms of volume, coconut shells had the highest absorption rate per unit volume at 0.65 mL/cm^3. Sawdust reached an absorption rate per unit volume of 0.58 mL/cm^3. Within the first 10 minutes of rainwater harvesting, sawdust reached its maximum retention volume of 98.7%, followed by coconut shells, oak bark, and loose pine cone scales at 76.6%, 75.1%, and 65.7%, respectively. Highly absorptive mulch is conducive for enhancing rainwater retention, and urban green space and mulch rainwater retention provide greater flexibility for coping up with intense rainstorms. Therefore, mulch has broad application prospects in urban green space, especially those in semi-arid regions. This study recommends adopting mulch as the third underlying layer after soil and plants in major urban green space.

INTRODUCTION

In 2014, China's Ministry of Finance and Ministry of Housing and Urban-Rural Development introduced the "Sponge City Construction" national policy, aiming to enhance cities' resilience against extreme climate (Li et al. 2016). Green space plays an irreplaceable role in promoting cities' resilience against disasters due to extreme climate. Suitable town planning for urban green space can effectively reduce the urban heat island effect, improve urban ventilation, and mitigate impacts from extremely hot climates (Liu et al. 2012). Natural sponges, such as forests, mountains, lakes, and wetlands, have superior permeability, storage, and purification capabilities that can facilitate the formation of a good aquatic ecosystem. The soil texture of natural woodland is loose, and soil is typically covered with a thick layer of fallen twigs and leaves. Additionally, large gaps are often formed by root systems and animal activities in soil, leading to soil runoff that results in a consistently high rainwater permeability rate. Under normal circumstances, there is rarely runoff in the soil, making it highly resilient to rainwater (Zhou et al. 2006).

Identifying methods for effectively enhancing the rainwater retention capability of urban green space is crucial for sponge city construction. Soil and plants are the two major underlying surfaces in urban green space. However, certain practical challenges exist for improving soil permeability and vegetation canopy interception capability. The primary challenge is that measures which involve high investment may damage the plant growing environment. Hence, identifying low investment measures that do not cause damage is highly important. Mulch is a new type of material used in urban green space that has developed rapidly in many European countries and the United States. Mulch is multifunctional, in that it improves the ecosystem, conserves soil, beautifies the environment, promotes tree health and growth, and achieves green landscaping and waste recycling. Mulch can retain and absorb rainwater while reducing soil water transpiration. It can significantly improve soil water content within a certain time frame after rain (Chen & Wang 2015). A 20 cm thick straw mulch layer can increase water content by over 30% in the first 20 cm of top soil. Water content in the first 40 and 60 cm of the top soil also increases, but the increase is lower at 20%-10%. These findings indicate that mulch can preserve water content in the top soil, but has a smaller impact on deeper soil (Wang 2008).

Currently, studies on mulch rainwater retention have focused on agricultural production areas, for example, hay and straw mulches can reduce rainwater runoff (Donjadee & Tawatchai 2016). In semi-arid regions, hay and straw mulches can significantly improve the rainwater utilization efficiency of orchards (Wang et al. 2015). It can reduce the kinetic energy of raindrops, enhance permeability, promote surface roughness, lower surface runoff speed, and protect soil resources; it is highly versatile and its functions are unmatched by any other non-woodland soil (Wu 2017). Additionally, mulch can also control weed growth, thus reducing landscape maintenance (Ruggeri et al. 2016). In terms of soil compaction reduction, when 20% of rice husks, sawdust, or bark by volume are compacted to soil, soil compac-tion is reduced to 50% of its original level (Yang et al. 2016).

Studies focusing on the rainwater retention of mulch in urban green space are scarce. Therefore, studying the rainwater retention capacity of mulch could provide support for selecting the best mulch type for the sponge city construction.

MATERIALS AND METHODS

This study focuses on four types of mulches: loose pine cone scales, broadleaf oak bark, coconut shells, and sawdust (Table 1). A digital scale (accuracy: ± 0.1 g) was used to measure the mass of mulch samples, which were first dehydrated in a blast oven to reach a final constant weight (Fig. 1). The mulch samples were then vacuum packed and sealed in individual bags, which were then put into a beaker to measure their natural compaction density from the volume of displaced water. A wet gauze was wrapped around each sample and this was soaked in a beaker filled with 2000 mL of water. At 10 minute intervals, the wrapped mulch samples were removed and drained until there was no more dripping, and then weighed. This was repeated every 10 minutes until the wrapped mulch samples were saturated and could not absorb any more water.

RESULTS AND ANALYSIS

Rainwater retention capacity of different mulch types based on mass ratio: Rainwater retention capacity varies widely between different mulch types (Fig. 2). In terms of mass ratio, the rainwater retention capacity of the different mulch types, from strong to weak, is as follows: coconut shells, sawdust, loose pine cone scales and oak bark. For coconut shells and sawdust, the absorbed water masses were 3.87 and 2.94 times their original mass, respectively. Both coconut shells and sawdust have high absorptive power that is conducive to improving rainwater retention on the ground, effectively lowering surface runoff, and possessing better compaction capacity, thereby effectively maintaining soil porosity. In contrast, loose pine cone scales and oak bark have lower absorptive power, at an order of 0.55 and 0.39 times of their original mass, respectively. Hay, however, has a very powerful absorption capacity of 427.9% of its own mass, and can hold up to 311.1 mm of rainfall (Sun 2009), but, due to aesthetic reasons, hay is not considered as appropriate for use in urban green space.

The above findings are of great significance to green projects that require consideration for quality. For example, in rooftop garden design, mulch types of higher absorptive power can be considered to ensure that a maximum amount of rainwater is absorbed, within a certain load limit.

Rainwater retention capacity of different mulch types based on volume ratio: The rainwater retention rate per unit volume of different mulch types provides a direct reference for sponge city construction. The rainwater retention capacity per unit volume of mulch, from strong to weak, is as follows: coconut shells, sawdust, loose pine cone scales, and oak bark (Fig. 3). The amount absorbed per unit volume is the highest in coconut shells, reaching 0.65 mL/cm^3, followed by sawdust at 0.58 mL/cm^3. Loose pine cone scales and oak bark are less absorptive, at 0.12 mL/cm^3 and 0.08

Loose pine cone scales Broadleaf oak bark Coconut shells Sawdust

Fig. 1: Various types of mulch samples.

Table 1: Basic characteristics of the mulch samples.

No.	Mulch type (abbr)	Specifications	Natural compaction density (g/cm^3)
1	Loose pine cone scales (LPCS)	Approximately 1 cm in chip form	0.209
2	Broadleaf oak bark (BOB)	Approximately 2-3 cm in nugget form	0.201
3	Coconut shells (CS)	Fibrous form	0.167
4	Sawdust (S)	Powder form	0.196

Table 2: Theoretical values of rainwater retention capacity of layers of different mulch thickness (paved in per unit area of green space).

Mulch name	Water retention amount in layers of different thickness paved (mm)		
	Thickness (100 mm)	Thickness (150 mm)	Thickness (200 mm)
Loose pine cone scales	12	18	24
Broadleaf oak bark	8	12	16
Coconut shells	65	97.5	130
Sawdust	58	87	116

Table 3: Mulch in urban green space and recommended mulch thickness.

Number	Location	Laying format	Thickness (cm)
1	Individual tree and shrub planting area	Fully paved to enclose the entire projected area of vegetation canopy	10-15
2	Plant community or woodland area	Fully paved to enclose all the edges of the plant community	10-15
3	Hedgerow planting area	Fully paved	5-10
4	Deep-rooted ground cover planting area	Fully paved	5-10
5	Vulnerable water erosion area	Fully paved	10-20
6	Mulched landscape	Fully paved	10

mL/cm^3 respectively. Biochar has good absorption capacity; its storage capacity can reach 0.45 mL/mL when it is used as filler material in retention ponds (Tang et al. 2016). To summarize, certain mulch types have higher rainwater retention capacity.

Vegetation canopy interception is an important water process in the soil-plant-atmosphere continuum (SPAC). The vegetation canopy interception capacity of most forests in Liupan Shan is 0.17-0.88 mm/LAI (Xu et al. 2010), and for denser plants, the vegetation canopy interception capacity during rainfall can reach 10-20 mm (Wang & Zhang 2009). Dang et al. (2008) studied *Franxinus mandschurica*, and found that the highest canopy interception during a single period of rainfall was 5.84 mm. In a study by Guo et al. (2014), the vegetation canopy interception capacity of garden plants was identified within a range of 3.2-7.9 mm. According to Table 2, paving a certain thickness of mulch can provide better rainwater retention capacity than vegetation canopy interception.

If a thickness of 15 cm of mulch is laid, the duration of rainwater retention by coconut shells under different rainfall intensities are shown in Fig. 4. Mulches are more resilient to rainwater retention and appropriate for widespread application in urban green space construction. The role of mulches in sponge city construction is significant, so mulches with high rainwater retention capacity, like coconut shells, should be adopted for coping with the peak rainy season.

Rainwater retention speed of different mulch types: The amounts of rainwater absorbed by the four mulch types are presented in Fig. 5. Within the first 10 minutes, sawdust had reached its maximum retention capacity of 98.7%, followed by coconut shells at 76.6%, oak bark at 75.1%, and loose pine cones scales at 65.7%. In the last 20 minutes, the rainwater retention capacity had plunged across all four mulch types, and plateaued. Loose pine cone scales and oak bark reached their maximum retention value at 50 minutes, whereas coconut shells reached their maximum retention value at 70 minutes.

APPLICATION

A complete industrial chain for organic mulch is fully formed in other developed countries, including product standards, product certification, industrial organizations, and produc-

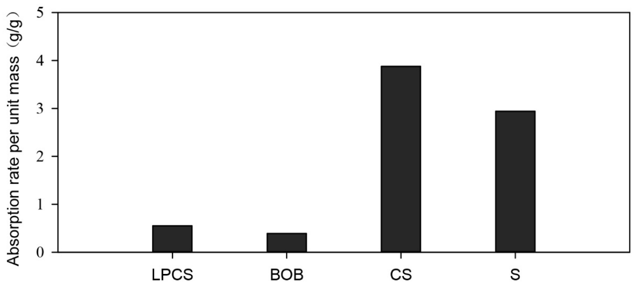

Fig. 2: Rainwater retention capacity of mulch (mass ratio).

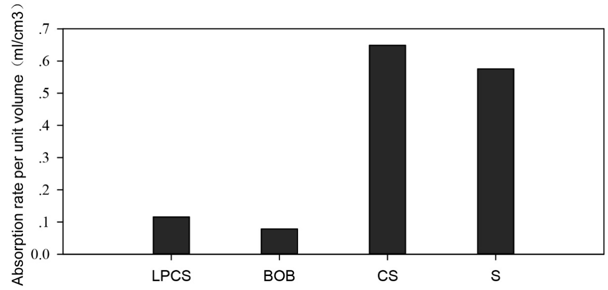

Fig. 3: Rainwater retention capacity of mulch (volume ratio).

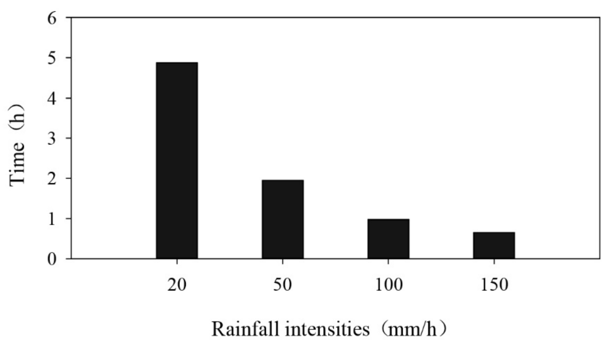

Fig. 4: Retention duration relative to different rainfall intensities when paved with 15 cm of coconut shell.

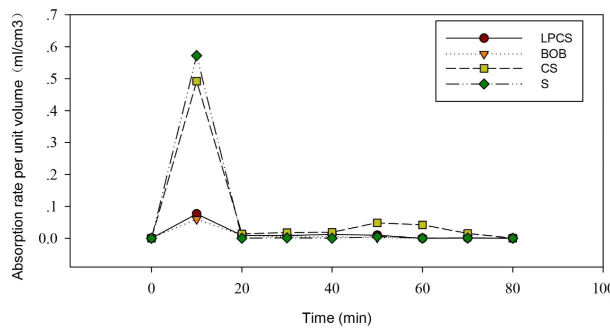

Fig. 5: Absorption rate per unit volume of mulch of different types at 10 minute intervals.

tion enterprises, and has been widely and effectively adopted. In the United States, large scale top soil replacement has occurred in woody plant areas in many parks and green space, using materials such as carbonized wood, wood nuggets, and bark powder (Wang 2015). Generally, as the size of the mulch pieces increases, the gaps between them increase and the water retention capacity of the mulch decreases, but the porosity improves. The rainwater retention capacity of larger mulch pieces, however, will improve as they decay over time, and their capacity to absorb heavy metals will also increase (Soleimanifar et al. 2016). Smaller mulch pieces generally have strong rainwater retention capacity, but mulch pieces that are too fine will impact soil ventilation when they are laid in a thick layer. Thus, an appropriate layer thickness should be selected according to different requirements.

Mulches can be replaced partially or fully depending on the situation. The depth of replacement should also be determined and adjusted considering factors including soil type and the depth of plant root systems (Table 3). For instance, thickness may be increased in semi-arid regions, but decreased in sticky soil or areas with frequent rainfall.

CONCLUSIONS

Mulches used in urban green space have been classified as hard and soft landscape for a long time, but soft landscape primarily includes lawn and ground cover plants. In sponge city construction, ground surface permeability needs to be strengthened to enhance its rainwater retention capacity, which can be achieved through mulching. Some types of mulches, such as coconut shells and sawdust, have good rainwater retention capacity, and thus have application value to cities for coping with heavy rainfall.

Additionally, reasonable combinations of mulch and other garden landscaping materials can form a good landscape. Therefore, this study recommends incorporating mulch as the third basic underlying layer after soil and plants in major urban green space. Changes should be made from merely using lawn as a ground covering to incorporate different combinations of mulch types to take advantage of their broad application prospects.

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