Improvement of Rainwater Infiltration Property and Its Effect on the Corresponding Storage Capacity of Soil in Urban Green Space

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Abstract: Urban green space whose soil permeability is the main factor affecting hydrological cycle plays a very important role in promoting rainwater infiltration, replenishing groundwater and reducing peak flow. In order to enhance the storage and infiltration ability of soil, different types and contents of conditioner are added to study the laws of the changes in permeability of various soils. The results showed that straw and sawdust can effectively increase the permeability coefficient of soil. According to the comparison under the same conditions, the improvement effects of straw is slightly better than sawdust, but no order of magnitude difference. The sandy soil reformed by 3.6% Straw or 4.2% Sawdust and the loam reformed by 29.5% Straw or 30.2% Sawdust can meet infiltration requires of rainwater whose rainstorm recurrence period is 10 years. The clay is not suitable for urban green space soils with higher rainwater storage and infiltration requirements. The reformed green space can effectively reduce the runoff peak flow and delay the generated time of the runoff. The higher the content of the modifier, the more obvious the advantage of promoting the hydrological cycle and reducing the runoff.

1 Introduction

As a natural rainwater storage and purification facility, urban green space not only helps enhance the infiltration of runoff to supplements the groundwater[1-3], but also reduces the speed of runoff. Besides, it can improve the removal efficiency of pollutants settlement and reduce the scour of soils by runoff[4-5]. Urban green space also plays a very important role in reducing the runoff peak flow[6-8]. The opinion of the State Council of the People's Republic of China on strengthening urban infrastructure construction emphasizes that it is very necessary to increase the ability of urban green spaces to gather runoff, replenish groundwater and purify ecology[9].

The function of urban green space to promote runoff circulation is achieved through soil infiltration. In cities such as Shanghai and Guangzhou, and even in some cities where there is not sufficient runoff, flooding caused by the ponding after heavy rain occurred. This is not only due to the fact that the design of the municipal drainage network is lagging behind, but also has something to do with that the urban green space have not really played a role in enhancing the infiltration of runoff. According to reports of urban green space, 37 percent of the urban green space soil in Nanjing whose infiltration rate is less than 0.333mm/min is slow infiltration levels[10]. The average infiltration rate of the urban green space soil in Shanghai Chenshan Botanical Garden is only 0.059mm/min and some of the samples were even 0 mm/min[11]. 78.9 percent of the urban green space soil in Heifei is belong to the medium and slow infiltration levels. In other words, it is only 21.1 percent of the urban green space soil in Heifei belong to the fast infiltration levels. It can be seen that the infiltration rate of the urban green space soil in China is generally low, which is mainly due to the low permeability coefficient. Therefore, it is very meaningful to use local conditioner to enhance the storage of runoff in urban green space.

2 materials and basic characteristics

Three different types of soil were selected for the test, which were taken from different regions in Yangzhou. The basic characteristics are shown in Table 1.

<table>
<thead>
<tr>
<th>number</th>
<th>Particle composition %</th>
<th>unit weight g·cm⁻³</th>
<th>The type of soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand</td>
<td>silt</td>
<td>clay</td>
<td></td>
</tr>
</tbody>
</table>

First Author: Lou keke, lkk_mail@163.com, Corresponding author: Wu zhengguang, male, Jiangsu, Professor (472761807@qq.com), mainly engaged in road works.
The straw and sawdust were chosen to be the conditioner, which are light, loose large porosity so that they have can increase the permeability and water retention. In addition, they have wide sources and low prices. These show that the straw and sawdust are ideal materials to be as the conditioner. Its physical properties are shown in Table 2.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>the physical properties of the conditioner</th>
</tr>
</thead>
<tbody>
<tr>
<td>the physical properties</td>
<td>straw</td>
</tr>
<tr>
<td>unit weight kg·m⁻³</td>
<td>192.4</td>
</tr>
</tbody>
</table>

3 Experiments

3.1 Preparation of soil samples
Different types of soil samples and the conditioners were mixed for use. Taking into account the different types of soil permeability coefficient varies greatly, the following quantities of mix were determined by the results of preliminary experiments:
- Sandy soil: sandy soil+5%、10%、15% straw(sawdust);
- Loam: loam+20%、25%、30% straw(sawdust);
- Clay soil: Clay soil+20%、30%、40% straw(sawdust).

3.2 Soil column filling
The different soil samples whose height is 20cm were added to the soil column. After that, it needs to be compacted 3 times manually and 2 times hydraulically to ensure uniform compaction.

3.3 Penetration test
Firstly, the upper valve was opened to ensure the constant head. At the same time, the bottom valve was opened. Then, the penetration test can be started. When the outlet The outlet began to discharge water, the electronic balance at the outlet could be cleared and this time is recorded as 0min. The readings of electronic balance were recorded at time intervals of 5, 10, 20, 30, 45, 65, 90, 120 (140, 160, 180) minutes. Finally, the volume of water samples were calculate by quality. In combination with Darcy's law, the computational formula of permeability coefficient is shown as Formula 1:

\[ K = \frac{V \cdot L}{A \cdot \Delta h \cdot t} \]  \hspace{1cm} (1)

4 Results and Discussion

4.1 Effect of Types and Dosages of the conditioners on the soil samples’ permeability coefficient

The rules of the permeability coefficient of the different soil samples that caused by types and dosages of the conditioners are shown as Figure 1.
permeability coefficient. With the increase of the conditioners, the permeability coefficient is gradually improved. This is owing to the permeability of the soil improved by the conditioners. The greater the dosages of the conditioners, the more obvious the improvement of soil permeability.

Under the same conditions, straw improved slightly better than sawdust. This is because the unit weight of the straw is smaller. Under the same quality conditions, the volume of the straw is larger, which make the straw dispersed more densely in the soil and form more micro-pores. Based on the above results, the relationship between the permeability coefficient and the dosages of the conditioners is fitted as shown in Table 3, Where K is the permeability coefficient and X is the dosages of the conditioner.

As shown in Table 3, the fitting correlation between the straw and sawdust dosages and the permeability coefficients of sandy soil and loam were more than 0.98, and the fitting correlation between the straw, sawdust dosages and clay permeability coefficient was above 0.83. This showed that it has a good fitting correlation between the permeability coefficient and the dosages of the conditioners. This is mainly because the conditioners enriched the porosity of the soil, and the porosity is closely related to the dosages of the conditioners.

### Table 3 the fitted equation and correlation of permeability coefficient and the dosages of the conditioner

<table>
<thead>
<tr>
<th>The type of soil</th>
<th>The type of the conditioner</th>
<th>the fitted equation</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>sandy soil</td>
<td>straw</td>
<td>K=0.0679X+0.4087</td>
<td>0.9978</td>
</tr>
<tr>
<td></td>
<td>sawdust</td>
<td>K=0.0627X+0.3903</td>
<td>0.982</td>
</tr>
<tr>
<td>loam</td>
<td>straw</td>
<td>K=0.0223X-0.0003</td>
<td>0.9979</td>
</tr>
<tr>
<td></td>
<td>sawdust</td>
<td>K=0.0218X-0.0054</td>
<td>0.997</td>
</tr>
<tr>
<td>Clay soil</td>
<td>straw</td>
<td>K=0.081X-0.032</td>
<td>0.8707</td>
</tr>
<tr>
<td></td>
<td>sawdust</td>
<td>K=0.079X-0.0379</td>
<td>0.8397</td>
</tr>
</tbody>
</table>

### 4.2 Requires for permeability in different rainstorm recurrence period

Taking Yangzhou as an example, a typical rainfall process was designed based on the Chicago flow process line model. A rainy peak coefficient of 0.4 and rain-fall time of 120 minutes was taken as an example. The computational formula of rainfall intensity in Yangzhou is shown as Formula 2[13]. The rules between rainfall intensity and rainfall duration are shown in Figure 2.

\[
q = \frac{8248.13(1 + 0.641 \log P)}{(t + 40.3)^{0.95}}
\]

(2)

**Figure 2** the rules between the rainfall intensity and the duration

The rainfall of the different rainstorm recurrence period are shown in Table 4.

### Table 4 the rainfall of the different rainstorm recurrence period

<table>
<thead>
<tr>
<th>recurrence period a</th>
<th>0.5</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall mm</td>
<td>38.57</td>
<td>47.80</td>
<td>57.02</td>
<td>62.41</td>
<td>69.21</td>
<td>78.43</td>
</tr>
</tbody>
</table>

The green space system can be considered as rainwater drainage systems whose infiltration capacity \( W_p \) is shown as Formula 3.

\[
W_p = K \cdot J \cdot A \cdot t
\]

(3)

The form of formula (3) can be transformed to get formula (4):

\[
K = \frac{W_p}{J \cdot A \cdot t}
\]

(4)

Assuming that rainfall at different rainstorm recurrence period requires complete infiltration within the rainfall duration. The minimum permeability coefficient to meet the requirements at different rainstorm recurrence period can be seen in Table 5.

**Table 5 the minimum permeability coefficient at different rainstorm recurrence period

<table>
<thead>
<tr>
<th>recurrence period a</th>
<th>0.5</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>permeability coefficient mm.min⁻¹</td>
<td>0.32</td>
<td>0.398</td>
<td>0.475</td>
<td>0.520</td>
<td>0.577</td>
<td>0.654</td>
</tr>
</tbody>
</table>

Combined with the previously the fitted equation, it can be seen that: for sandy soil, the soil reformed by 3.6% Straw or 4.2% Sawdust can meet infiltration requires of rainwater whose rainstorm recurrence period is 10 years. For loam, the soil reformed by 18% straw or 18.5% sawdust can meet infiltration requires of rainwater whose rainstorm recurrence period is 1 years. The loam reformed by 23.5% straw or 24.1% sawdust can meet infiltration requires of rainwater whose rainstorm recurrence period is 3 years. The loam reformed by 29.5% straw or 30.2% sawdust can meet infiltration requires of rainwater whose rainstorm recurrence period is 10 years. For clay soil, the soil reformed by 40% straw or sawdust can not meet infiltration requires of rainwater whose rainstorm recurrence period is 0.5 years. From the view of maintaining soil biodiversity and cost, the dosage of straw or sawdust should not continue to increase. So the clay is not suitable for urban green space soils with higher rainwater storage and infiltration requirements.
The dosage of conditioner under different permeability requirements are shown in Table 6.

<table>
<thead>
<tr>
<th>recurrence period</th>
<th>0.5</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>permeability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>coefficient mm.min⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>straw 0.321</td>
<td>sawdust 0.398</td>
<td>straw 0.475</td>
<td>sawdust 0.520</td>
<td>straw 0.577</td>
<td>straw 0.654</td>
<td></td>
</tr>
</tbody>
</table>

The dosages of the conditioner %

| straw dusty straw sawdust straw sawdust straw sawdust straw sawdust straw sawdust |
|---|---|---|---|---|---|---|---|---|---|
| sandy soil 0 | 0 | 0 | 1 | 1.4 | 1.6 | 2 | 2.5 | 3 | 3.6 | 4.2 |
| loam 14.5 | 15 | 18 | 21.4 | 22 | 23.5 | 24.1 | 26 | 26.7 | 29.5 | 30.2 |
| Clay soil - | - | - | - | - | - | - | - | - | - | - |

4.3 Effect on soil rainwater Storage Capacity before and After Improvement

In order to study the impact of green space soils before and after improvement on rainwater infiltration and peak flow reduction. The rainstorm recurrence period in Yangzhou was taken as an example. The calculation of the runoff discharge and the peak reduction during the rainfall whose rainstorm recurrence period is 2 years, 3 years, 5 years, and 10 years. A green land with an area of 1ha was taken as an example for calculation, where the low elevation greenbelt area accounts for 10% and the concave depth is 100mm. The original sandy soil, sandy soil reformed by 5% straw and sandy soil reformed by 10% straw were compared to analyse the impact of green space soils before and after improvement on rainwater infiltration and peak flow reduction.

![Figure 3](image-url)

Figure 3 the rules between runoff flow and duration under different recurrence period

Through the analysis of Figures 3a-3d, it was found that compared with the original soil, the soil reformed by 5% straw could increase the peak flow reduction by 27%, 24%, 21%, 18% under the recurrence period of 2a, 3a, 5a, and 10a. The soil reformed by 10% straw could increase the peak flow reduction by 97%, 76%, 56%, 40% under the recurrence period of 2a, 3a, 5a, and 10a. It can be seen that the green space system has the capacity of seepage for runoff under different recurrence period. It can effectively reduce the runoff peak flow and delay the generated time of the runoff. The improved soil has more advantages than the original soil in terms of rainwater infiltration. The larger the amount, the greater the advantage. When the recurrence period is 2 years, the green space soil reformed with 10% straw will not generate runoff. Even if the recurrence period is 5 years or 10 years, the improved soil has the effect of significantly reducing peak flow of runoff.

5 Conclusion

The mix of soil and straw and sawdust can greatly enrich the porosity of the soil. Through adding the different
types and dosages of conditioners, the rules of different kinds of soil permeability and the effects on runoff and seepage were studied. The following conclusions were obtained:

(1) straw and sawdust are both superior conditioners that effectively increase the permeability coefficient of soil. According to the comparison under the same conditions, the improvement effects of straw is slightly better than sawdust, but no order of magnitude difference.

(2) it has a good fitting correlation between the permeability coefficient and the dosages of the conditioners. for sandy soil, the soil reformed by 3.6% Straw or 4.2% Sawdust can meet infiltration requires of rainwater whose rainstorm recurrence period is 10 years. For loam, the soil reformed by 18% straw or 18.5% sawdust can meet infiltration requires of rainwater whose rainstorm recurrence period is 1 years. The loam reformed by 23.5% straw or 24.1% sawdust can meet infiltration requires of rainwater whose rainstorm recurrence period is 3 years. The loam reformed by 29.5% straw or 30.2% sawdust can meet infiltration requires of rainwater whose rainstorm recurrence period is 10 years. For clay soil, it is not suitable for urban green space soils with higher rainwater storage and infiltration requirements.

(3) The reformed green space can effectively reduce the runoff peak flow and delay the generated time of the runoff. The higher the content of the modifier, the more obvious the advantage of promoting the hydrological cycle and reducing the runoff.

Acknowledgment

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References

7. Kshama Gupta, Arijit Roy, Kanishka Luthra, Sandeep Maithani, Mahavir. GIS based analysis for assessing the accessibility at hierarchical levels of urban green spaces. Urban Forestry & Urban Greening, 2016, 1: