Sponge Cities Program in China: Key Techniques for Spongy Grassland

Prof. Dr. Zhaolong Wang
School of Agriculture & Biology, Shanghai Jiaotong University
turf@sjtu.edu.cn
上海 ≈ above the sea
城市看海：watching urban sea?
Sponge Cities Program

- 2013/03/25: Chinese State Council: Construction of urban drainage facilities.
- 2014/03: President Xi: Sponge Cities.
- 2015/10/11: State Council: Guides on promoting the construction of sponge cities.
- 2016/04/22: + 14 cities for the second pilot.
- > 66 billions RMB investment from the government (subsidy to 16 pilot cities).
Sponge Cities Program

- About 130 Chinese cities formulated the sponge city construction programs by 2015.
- About 658 Chinese cites is constructing for sponge city projects in 2017.
- Annually investment for sponge city programs is about 400 billions RMB.
2017/03/09 (Ministry of Construction): 36 techniques/products recommended for sponge cities.

- Rainwater collection (3)
- Porous pavement (5)
- **Green roofs (3)**
- Water-storing facilities (2)
- Ancillary facilities (4)
- **Vegetation buffer zone (1)**
- Sewage interception facilities (1)
- Purification of rain sewage (3)
- Water treatments (5)
- Planning & designing (2)
- Monitoring and management (2)
- Permeable pipes (2)
- Pipelines (3)
Greenroofs

- Extensive greenroofs — sedums.
- Extensive greenroofs — *Callisia repens*.
- Container greenroofs
Vegetation buffer zone

Multi-Eco-Bank infiltration & purification.
Rainwater purifications

- Ecological purification technology of urban rainwater.
- Constructed wetland: vertical flow filter bed.
- *In situ* decentralized rain water treatment.
2016/02/08 (Ministry of Construction): 35 techniques/products recommended for sponge cities.

- Rainwater collection (7)
- Porous pavement (4)
- **Green roofs (3)**
- Water-storing facilities (2)
- Ancillary facilities (4)
- Purification of rain sewage (1)
- Water treatments (5)
- Monitoring and management (5)
- Permeable pipes (1)
- Pipelines (3)
Greenroofs

- Special-shaped layer planting bag.
- Root barrier & waterproofing system.
- Automatic water storage tank for greenroofs
Urban wetlands
Rain garden
Problems for plants

- Ponding during the rain season, hydrophytes and hygrophytes only for rain gardens.
- What about them during the dry season?
- Irrigation to maintain the water layer?—contradictions with the municipal water use
Lower grassland

Collecting water from surrounding buildings and roads
Grassland higher than road surface
Rainfall water directly go to the drainage

Grassland lower than road surface
Rainfall water to grassland
Grassland infiltration & retention
Excess go to drainage
Problems of lower grassland

- Short-time period of flooding/waterlogged during rain season.
- Mostly xerophyte turfgrasses.
- Flooding tolerance of turfgrass species?
Objection from landscape experts

- Waterlogged environment will kill landscape plants
- Rainwater pollutants will negative to landscape plant growth.
- Urban grassland has limited capacity of water retention.
- Lower grassland will lose the recreation functions.
Hangzhou

Grassed swales
Silt up after rainfall
What?
Water reservoir?
Lower grassland?
Researches on Spongy Grassland

- Flooding tolerance of turfgrass species
- Improvement of water infiltration & retention
- Spongy Grassland—integration of rainwater storage and utilization
I. Flooding tolerance of turfgrass species

- Turfgrass species: tall fescue, creeping bentgrass, perennial ryegrass, Kentucky bluegrass
- 24 d of waterlogged stress (20 mm above the soil surface)
- 13 d of recovery after stress.
Flooding tolerance of turfgrass species

24 d waterlogged stress

Tall fescue: no turf quality decline

图 2-1 不同淹水处理下各草种的目测质量
Fig.2-1 The visual quality of all turfgrasses under different waterlogging stress treatments
Yellowing leaf ratio

24 d waterlogged stress

Tall fescue & perennial ryegrass

图 2-2 不同淹水处理下各草种的叶片枯黄率

Fig.2-2 The leaf death rate of all turfgrasses under different waterlogging stress treatments
Root length

24 d waterlogged stress

Tall fescue & Creeping bentgrass

Fig.2-3 The roots’ length of all turfgrasses under different waterlogging stress treatments
Plant height

24 d waterlogged stress

Tall fescue & Creeping bentgrass

图 2-4 不同淹水处理下各草种的植株高度

Fig.2-4 The plant height of all turfgrasses under different waterlogging stress treatments
Turf Quality Recovery

13 d recovery after waterlogged stress

- 草地早熟禾 Poa pratensis
- 高羊茅 Festuca arundinacea

- 匙叶剪股颖 Agrostis stolonifera
- 多年生黑麦草 Lolium perenn
Conclusion

- Tall fescue has better waterlogged tolerance than creeping bentgrass, perennial ryegrass, and Kentucky bluegrass.

- Depth of flooding, and how long?
Waterlogged stress:
- 0 mm water level above the soil surface
- 40 mm water level above the soil surface (half plants in water)
- 80 mm water level above the soil surface (whole plants in water)
- Control: No stress at all.
### 不同淹水深度下高羊茅的耐淹特性

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Turf quality</th>
<th>Leaf death rate/ %</th>
<th>Root length/ cm</th>
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<tr>
<td>CTL</td>
<td>8.6 a</td>
<td>3.30 c</td>
<td>31.3 a</td>
</tr>
<tr>
<td>0 mm</td>
<td>7.8 b</td>
<td>5.83 c</td>
<td>28.3 ab</td>
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<tr>
<td>40 mm</td>
<td>6.4 c</td>
<td>14.24 b</td>
<td>25.3 ab</td>
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<tr>
<td>80 mm</td>
<td>3.2 d</td>
<td>88.33 a</td>
<td>22.8 b</td>
</tr>
</tbody>
</table>

注：数字后的小写字母代表不同处理之间的显著性差异。
After 42 d

Fig. 3-5 The biomass of Tall fescue under different flooding stress treatments
图 3-1 不同淹水深度下高羊茅叶绿素含量的变化
Fig.3-1 The change of Chlorophyll content in leaves of Tall fescue under different flooding stress treatments
Souble sugar content

图 3-3 不同淹水深度下高羊茅可溶性糖含量的变化

Fig.3-3 Change of soluble sugar content in leaves of Tall fescue under different flooding stress treatments
淹水期间

图 3-2 不同淹水深度下高羊茅丙二醛含量的变化

Fig.3-2 The change of MDA content in leaves of Tall fescue under different flooding stress treatments
Electrolyte leakage

图 3-4 不同淹水深度下高羊茅相对电导率的变化

Fig.3-4 The change of electric conductivity in leaves of Tall fescue under different flooding stresses
Recovery of turf quality

20 d of recovery

Graph showing the recovery of turf quality over 20 days with different conditions.
Conclusion

- Tall fescue can tolerate 0 mm waterlogged stress for 42 d.
- Tall fescue can tolerate 40 mm waterlogged stress for 35 d.
- Tall fescue can tolerate 80 mm waterlogged stress for 28 d.
- After 42 d of <40 mm waterlogged stress, plant could be recovered after 20 d.
- But the plants under 80 mm waterlogged stress could not be recovered.
II. Researches on water infiltration & retention

- Precipitation
- Soil infiltration & retention
- Runoff
  - Runoff = precipitation – (infiltration + retention)
- Grassland infiltration & retention is critical to reduce runoff.
Soil amendments

- Organic amendments (peat moss) is popular used to improve soil water retention, but decreased soil infiltration rate significantly.
- Looking for better soil amendments to improve both water retention and infiltration.
Soil amendments

- Coral sand
- Vermiculite
- Perlite (Clite)
- Diatomite (Axis)
- Ceramsite (Profile)
- Biochar (Rice-husk)
- Peat moss
Tab.2-1 The particle size distribution of soil amendments

<table>
<thead>
<tr>
<th>Samples</th>
<th>2mm</th>
<th>0.5mm</th>
<th>0.25mm</th>
<th>0.15mm</th>
<th>0.05mm</th>
<th>Total sand 0.05-2mm</th>
<th>silt 0.002-0.05mm</th>
<th>clay 0.002mm</th>
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<tr>
<td>Biochar</td>
<td>32 ± 0.7</td>
<td>36 ± 0.3</td>
<td>25 ± 0.1</td>
<td>4 ± 0.2</td>
<td>1 ± 0.1</td>
<td>1 ± 0.0</td>
<td>67 ± 0.2</td>
<td>1 ± 0.0</td>
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<tr>
<td>Coral#1</td>
<td>0 ± 0.0</td>
<td>42 ± 0.3</td>
<td>41 ± 0.1</td>
<td>14 ± 0.1</td>
<td>0 ± 0.0</td>
<td>0 ± 0.0</td>
<td>99 ± 0.0</td>
<td>1 ± 0.1</td>
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<tr>
<td>Coral #2</td>
<td>0 ± 0.0</td>
<td>45 ± 0.1</td>
<td>50 ± 0.1</td>
<td>0 ± 0.0</td>
<td>0 ± 0.0</td>
<td>100 ± 0.0</td>
<td>0 ± 0.0</td>
<td>0 ± 0.0</td>
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<td>Vermiculite</td>
<td>9 ± 0.2</td>
<td>27 ± 0.3</td>
<td>38 ± 0.4</td>
<td>6 ± 0.1</td>
<td>11 ± 0.2</td>
<td>6 ± 0.1</td>
<td>88 ± 0.3</td>
<td>3 ± 0.0</td>
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<td>CLITE</td>
<td>0 ± 0.0</td>
<td>24 ± 0.1</td>
<td>34 ± 0.1</td>
<td>30 ± 0.2</td>
<td>6 ± 0.1</td>
<td>5 ± 0.1</td>
<td>99 ± 0.1</td>
<td>1 ± 0.0</td>
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<td>AXIS</td>
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<td>58 ± 0.5</td>
<td>24 ± 0.6</td>
<td>4 ± 0.2</td>
<td>1 ± 0.0</td>
<td>99 ± 0.2</td>
<td>0 ± 0.0</td>
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<td>PROFILE</td>
<td>0 ± 0.0</td>
<td>39 ± 0.5</td>
<td>58 ± 0.7</td>
<td>2 ± 0.2</td>
<td>1 ± 0.1</td>
<td>100 ± 0.2</td>
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<td>Peat moss</td>
<td>13 ± 0.1</td>
<td>10 ± 0.2</td>
<td>21 ± 0.2</td>
<td>30 ± 0.1</td>
<td>9 ± 0.1</td>
<td>15 ± 0.1</td>
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<td>0.1</td>
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<tr>
<td>USGA</td>
<td>≤10%</td>
<td>(≤3%砾石)</td>
<td>≥60%</td>
<td>≥20%</td>
<td>≥5%</td>
<td>≥5%</td>
<td>≤3%</td>
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<td>Samples</td>
<td>hydraulic conductivity (cm/h) Total</td>
<td>porosity (%)</td>
<td>field capacity (%)</td>
<td>bulk density (g/cm³)</td>
<td>K + retention (mg/kg)</td>
<td>NO3-retention (mg/kg)</td>
<td>pH</td>
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<td>-------------</td>
<td>------------------------------------</td>
<td>--------------</td>
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<td>----------------------</td>
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<tr>
<td>Biochar</td>
<td>146 ± 0.3a</td>
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<td>57 ± 0.4b</td>
<td>27 ± 0.2c</td>
<td>250 ± 0.5b</td>
<td>0.2 ± 0.0g</td>
<td>12353 ± 4 942 ± 3b 9.7a</td>
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<tr>
<td>Coral#1</td>
<td>78 ± 0.2f</td>
<td>49 ± 0.5dc</td>
<td>40 ± 0.2cd</td>
<td>9 ± 0.5f</td>
<td>28 ± 0.3g</td>
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<td>Coral #2</td>
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<td>49 ± 0.4cd</td>
<td>36 ± 0.5cd</td>
<td>13 ± 0.3e</td>
<td>25 ± 0.2h</td>
<td>1.5 ± 0.0b</td>
<td>16585 ± 9 23.8 ± 0.5 7.9b</td>
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<tr>
<td>CLITE</td>
<td>120 ± 0.3c</td>
<td>85 ± 0.4a</td>
<td>30 ± 0.2d</td>
<td>55 ± 0.2a</td>
<td>219 ± 0.4c</td>
<td>0.1 ± 0.0h</td>
<td>3566 ± 6.4h 231 ± 0.7f 7.6c</td>
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<td>AXIS</td>
<td>116 ± 0.7d</td>
<td>81 ± 0.5ab</td>
<td>46 ± 0.3c</td>
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<td>108 ± 0.5e</td>
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<td>16838 ± 3.5b 1539 ± 3.5a 7.6c</td>
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<td>PROFILE</td>
<td>123 ± 0.2b</td>
<td>67 ± 0.3ab</td>
<td>32 ± 0.5d</td>
<td>35 ± 0.5b</td>
<td>38 ± 0.5f</td>
<td>0.8 ± 0.0d</td>
<td>4222 ± 4.7g 317.0 ± 1.5 6.5f</td>
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<td>Vermiculite</td>
<td>14 ± 0.5h</td>
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<td>64 ± 0.1b</td>
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<td>146 ± 0.1d</td>
<td>0.4 ± 0.0e</td>
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<td>Peat moss</td>
<td>10 ± 0.2i</td>
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<td>74 ± 0.3a</td>
<td>9 ± 0.3f</td>
<td>286 ± 0.6a</td>
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<td>14430 ± 6.5d 798 ± 3.5c 6.7e</td>
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<td>Sand</td>
<td>73 ± 0.3g</td>
<td>42 ± 0.2d</td>
<td>19 ± 0.1e</td>
<td>23 ± 0.2d</td>
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<td>1.6 ± 0.1a</td>
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<td>LSD</td>
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<td>0.7</td>
<td>0.1</td>
<td>9.3               3.8    0.1</td>
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</tbody>
</table>
Bulk density improvement

![Graph showing bulk density improvement](image)
Water retention improvement

![Water retention improvement graph](image)
Hydraulic conductivity improvement

USGA recommendation: $\geq 6$ inches/hr (15 cm/h)
K⁺ retention improvement

![Graph showing K⁺ retention improvement with different soil amendments.](chart.png)
NO$_3^-$ retention improvement

![Graph showing NO$_3^-$ retention improvement with different soil amendments.](image)

- Soil amendments: CLITE, AIXS, PROFILE, BK GL
- Graph shows NO$_3^-$ retention in mg/kg against soil amendments radio (V/V, %)
Conclusion

- Improvements of bulk density, water retention, nutrients retention...
- Biochar $\leq 15\%$
- AXIS $\leq 15\%$
- CLITE $\leq 15\%$
- Peat moss $\leq 10\%$
- PROFILE $\leq 20\%$
Effects on bentgrass establishment

10% amendment
# Leaf emergence of creeping bentgrass

<table>
<thead>
<tr>
<th>Amendments</th>
<th>Leaf age</th>
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<tr>
<td></td>
<td>10d</td>
</tr>
<tr>
<td>PROFILE</td>
<td>1.5a</td>
</tr>
<tr>
<td>AXIS</td>
<td>1.3bc</td>
</tr>
<tr>
<td>Biochar</td>
<td>1.3bc</td>
</tr>
<tr>
<td>CLITE</td>
<td>1.2c</td>
</tr>
<tr>
<td>Peat moss</td>
<td>1.3b</td>
</tr>
<tr>
<td>Sand</td>
<td>1.2c</td>
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<tr>
<td>LSD0.05</td>
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<tr>
<td>Amendment</td>
<td>17d</td>
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<tr>
<td>--------------</td>
<td>-------</td>
</tr>
<tr>
<td>PROFILE</td>
<td>1.5a</td>
</tr>
<tr>
<td>AXIS</td>
<td>1.4bc</td>
</tr>
<tr>
<td>Biochar</td>
<td>1.3bcd</td>
</tr>
<tr>
<td>CLITE</td>
<td>1.3cd</td>
</tr>
<tr>
<td>Peat moss</td>
<td>1.4ab</td>
</tr>
<tr>
<td>Sand</td>
<td>1.2d</td>
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<tr>
<td>LSD0.05</td>
<td>0.1</td>
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</table>
## Vertical growth rate of creeping bentgrass

<table>
<thead>
<tr>
<th>Amendment</th>
<th>Growth rate (mm/d)</th>
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<tbody>
<tr>
<td></td>
<td>10d</td>
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<tr>
<td>PROFILE</td>
<td>1.93</td>
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<tr>
<td>AXIS</td>
<td>1.68</td>
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<tr>
<td>Biochar</td>
<td>1.55</td>
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<tr>
<td>CLITE</td>
<td>1.54</td>
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<td>Peat moss</td>
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<td>Sand</td>
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<tr>
<td><strong>LSD0.05</strong></td>
<td>0.14</td>
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</table>
# Turf coverage of creeping bentgrass

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<th>Amendment</th>
<th>10d</th>
<th>17d</th>
<th>24d</th>
<th>31d</th>
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</thead>
<tbody>
<tr>
<td>PROFILE</td>
<td>25.6a</td>
<td>35.0a</td>
<td>71.4a</td>
<td>91.4a</td>
</tr>
<tr>
<td>AXIS</td>
<td>22.8b</td>
<td>29.6b</td>
<td>62.5d</td>
<td>73.8b</td>
</tr>
<tr>
<td>Biochar</td>
<td>19.4c</td>
<td>25.1c</td>
<td>53.7c</td>
<td>69.2b</td>
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<tr>
<td>CLITE</td>
<td>19.0c</td>
<td>24.6c</td>
<td>52.2c</td>
<td>68.8b</td>
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<tr>
<td>Peat moss</td>
<td>25.3ab</td>
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<td>69.4a</td>
<td>88.1a</td>
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<td>16.8c</td>
<td>20.6d</td>
<td>41.5d</td>
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<td>3.2</td>
<td>4.7</td>
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# Plant biomass of creeping bentgrass

<table>
<thead>
<tr>
<th>Amendment</th>
<th>Biomass (mg/plant)</th>
<th>Root length (cm)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Shoot</td>
</tr>
<tr>
<td>PROFILE</td>
<td>6.6a</td>
<td>5.1a</td>
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<tr>
<td>AXIS</td>
<td>5.3b</td>
<td>4.4bc</td>
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<tr>
<td>Biochar</td>
<td>5.1b</td>
<td>4.3c</td>
</tr>
<tr>
<td>CLITE</td>
<td>4.0c</td>
<td>2.9d</td>
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<td>Peat Moss</td>
<td>5.3b</td>
<td>4.6b</td>
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<tr>
<td>Sand</td>
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<td>1.9e</td>
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<tr>
<td>LSD0.05</td>
<td>0.2</td>
<td>0.2</td>
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</table>
Conclusion

- 10% of amendments improved turf establishment of creeping bentgrass.
- Effects order: PROFILE > Peat moss > AXIS > Biochar > CLITE
Effects on drought tolerance

25d of drought stress

AIXS

PROFILE

0% 5% 10% 15% CTL

0% 5% 10% 15% CTL

0% 5% 10% 15% CTL

0% 5% 10% 15% CTL
## Growth rate under drought stress

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Ratio%</th>
<th>0d</th>
<th>5d</th>
<th>10d</th>
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<td>Biochar</td>
<td>5</td>
<td>1.0def</td>
<td>0.7fh</td>
<td>0.1f</td>
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<tr>
<td></td>
<td>10</td>
<td>1.0def</td>
<td>0.9e</td>
<td>0.2f</td>
</tr>
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<td></td>
<td>15</td>
<td>1.0cdef</td>
<td>0.6fh</td>
<td>0.2f</td>
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<tr>
<td></td>
<td>5</td>
<td>1.0ef</td>
<td>1.0de</td>
<td>0.6ab</td>
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<tr>
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<td>10</td>
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## Leaf electrolyte leakage under drought stress

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## Leaf chlorophyll content under drought stress

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Conclusion

- All amendments improved turfgrass drought tolerance.

- Effects order: CLITE > AXIS > PROFILE > Biochar
Effects on nutrients leaching
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<td>mg/L   Lose %</td>
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Effects on K leaching

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Conclusion

- All amendments decreased nutrients leaching.
- Effects order on N leaching: CLITE > Peat moss > Biochar > PROFILE > AXIS
- Effects order on K leaching: Peat moss > CLITE > Biochar > PROFILE > AXIS
III. Spongy Grassland

- Spongy grassland for water storage:
  - Canopy retention =
    \[(\text{Saturated moisture} - \text{wilting point}) \times \text{canopy biomass}\]
  - Soil water retention =
    \[(\text{Field capacity} - \text{natural drying water content}) \times \text{soil depth}\]
  - Water storage facilities =
    Additional water storage facilities attached with grassland.
Runoff

Main factors:

- Precipitation intensity.
- Infiltration rate of grassland
- Slope

Runoff = Precipitation – Canopy Retention – Soil (infiltration + retention)
How to design and construction of Spongy Grassland—integrative spongy grassland in rainwater storage and utilization

- Maximizing rain water storage capacity ≥
- Plant evaportranspiration during sunny days
Key 1

Select flooding tolerance plants with lower ET
Key 2

- Constructed the highly infiltration soil to reduce runoof.
- Infiltration rate $>>$ precipitation.
- If not…
Improvement of water retention

![Graph showing water retention improvement with different soil amendments radio (V/V,%)](image)

- **Soil amendments radio (V/V,%)**
- **Water retention (%)**

- **稻壳炭粒**
- **CLITE**
- **AIXS**
- **PROFILE**
- **草炭**
Improvement of infiltration

Saturated hydraulic conductivity (%) vs. Soil amendments radio (V/V,%)
Key 3

- Water retention in grassland ≥ Plant water consumption

- Grassland water retention =
  Plant tissue retention + soil retention + additional facility

- Plant water consumption = Evaportranspiration × days
  ※ Plant species
  ※ Local weather
Water retention of various soils

田间持水量（%）

砂土 | 砂壤土 | 壤土 | 粘土 | 草炭 | 生物炭
Water retention improvement

![Graph showing water retention improvement with different soil amendments](image-url)
Key 4

- Contradiction between soil water and air?
- Rain days: how to keep enough air in rootzone?
- Dry days: capillary movement of stored water supplied to plant roots.
Key 5

Surface dry of grassland for recreation functions.
Case study 1

- Beijing: sandy loam soil
- Road : grassland = 4 : 1
- Rain water on road directly run into grassland.
- No runoff under 15 mm/h precipitation.
- No irrigation for 10 days.
Design

Soil testing:

- soil infiltration rate = 32.4 mm/h;
- Field capacity = 25%.

- Turfgrass: Kentucky bluegrass
- Soil layer: 300 mm.
Design

- Precipitation 15 mm/h < soil infiltration rate 32.4 mm/h.
- All rain water infiltrated into soil, no runoff from grassland.
- Constructed road area 4 times of the grassland.
- Runoff into grassland = 4 × 15 mm/h = 60 mm/h > infiltration rate. *Temporary waterlogged!*
- Water retention capacity of grassland = 300 mm × 25% = 75 mm.
- = 60 mm from road runoff + grassland 15 mm.
- > Retention capacity will go to the drainage.
Water consumption

- Average ET of Kentucky bluegrass was 6 mm/d.
- Grassland water retention: 75 mm.
- Days of water consumption by grass: 75 / 6 = 12.5 d
- No irrigation required in 12.5 d.
Case study 2

- Shanghai: Clay loam soil.
- Road : grassland = 2 : 1
- Rain water on road directly run into grassland.
- No runoff under 30 mm/h precipitation.
- No irrigation for 20 days.
Design

Soil testing:

- Soil infiltration rate = 5 mm/h. << 30 mm/h precipitation. *Required soil amendment.*

- **Soil : sand : peat moss = 50: 45: 5.**

- Amended Soil infiltration rate = 35 mm/h > 30 mm/h precipitation.

- Field capacity = 30%.

- Turfgrass: Bermudagrass

- Soil layer: 300 mm.
Design

- Precipitation 30 mm/h < soil infiltration rate 35 mm/h.
- All rain water infiltrated into soil, no runoff from grassland.
- Constructed road area 2 times of the grassland.
- Runoff into grassland = $2 \times 30 \text{ mm/h} = 60 \text{ mm/h} >$ infiltration rate. *Temporary waterlogged!*
- Water retention capacity of grassland = $300 \text{ mm} \times 30\% = 90 \text{ mm}$.
- $= 60\text{ mm from road runoff} + \text{grassland 30 mm}$.
- $> \text{Retention capacity will go to the drainage.}$
Water consumption

- Average ET of Bermudagrass was 4 mm/d.
- Grassland water retention: 90 mm.
- Days of water consumption by grass: \( \frac{90}{4} = 22.5 \) d
- No irrigation required in 22.5 d.

- Local weather data showed that dry-day-period was 22 d in 5-year-return.
Thanks