# Sponge Cities Program in China: Key Techniques for Spongy Grassland

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# 上海 ≈ above the sea

# 城市看海：watching urban sea?

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# Sponge Cities Program

- 2013/03/25: Chinese Sate Council: Construction of urban drainage facilities.
- 2014/03: President Xi: Sponge Cities.
- 2014/10/22:  Ministry of Construction: Guideline for sponge city construction -- rainwater system with low impact development
- 2015/04: 16 pilot cities for sponge cities construction
- 2015/10/11: Sate 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.

财　　政　　部
住房城乡建设部 文件
水　　利　　部

财建〔2014〕838 号

财政部 住房城乡建设部 水利部关于
开展中央财政支持海绵城市
建设试点工作的通知

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# Techniques & Products (I)

- 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)

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# Greenroofs

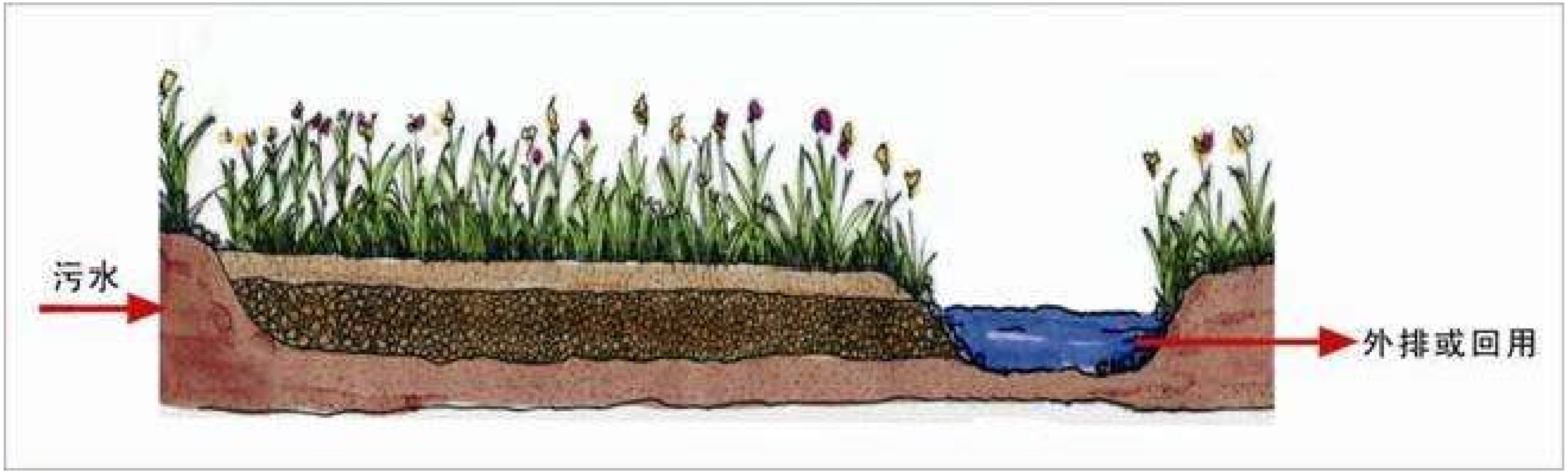
- Extensive greenroofs — sedums.
- Extensive greenroofs — *Callisia repens*.
- Container greenroofs

# Vegetation buffer zone

- Multi-Eco-Bank infiltration & purification.

# Rainwater purfications

- Ecological purification technology of urban rainwater.
- Constructed weland: vertical flow filter bed.
- *In situ* decentralized rain water treatment.



# Techniques & Products (II)

- 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

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# 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?

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# Water reserivoir?

# 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

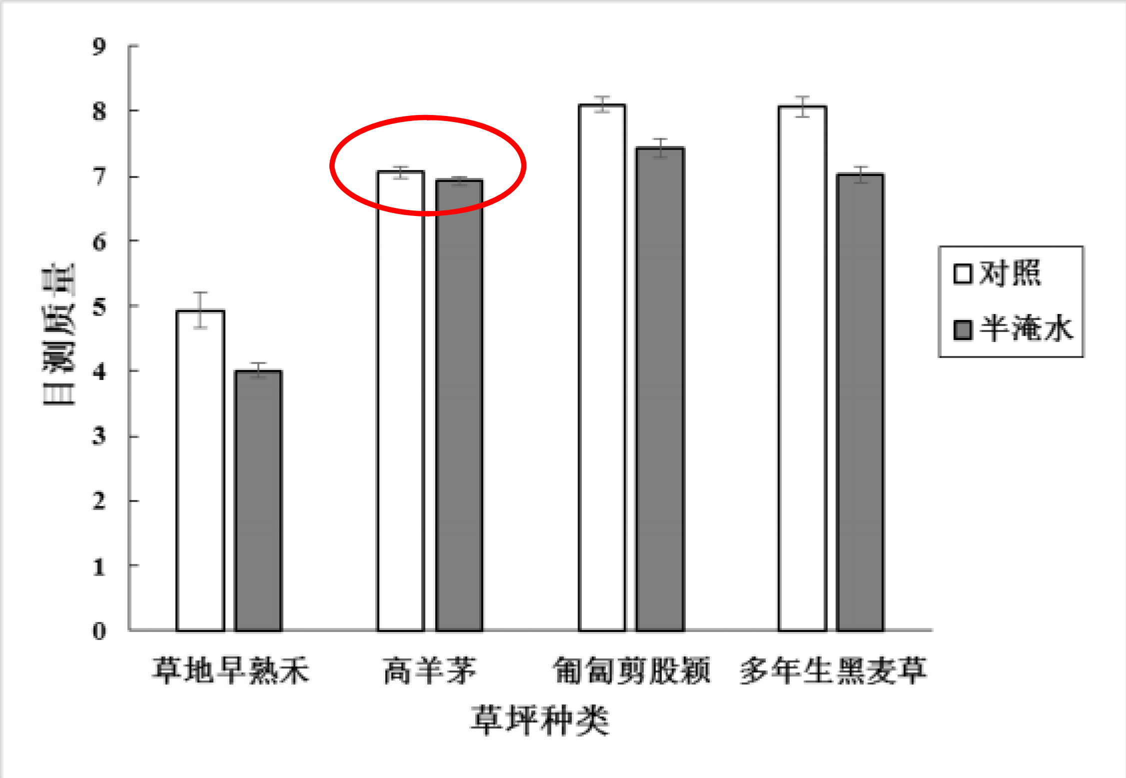


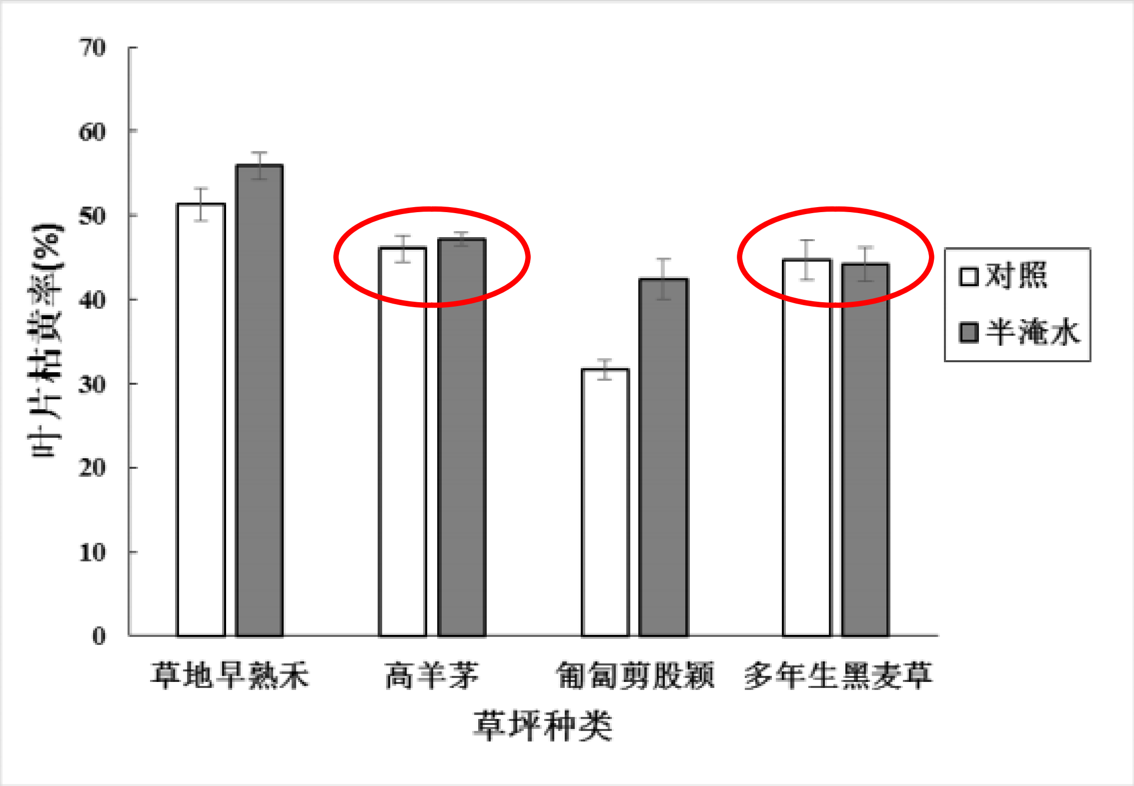

图 2-1　不同淹水处理下各草种的目测质量

**Fig.2-1 The visual quality of all turfgrasses under different waterlogging stress treatments**

Tall fescue:
no turf quality decline

# Yellowing leaf ratio

24 d waterlogged stress



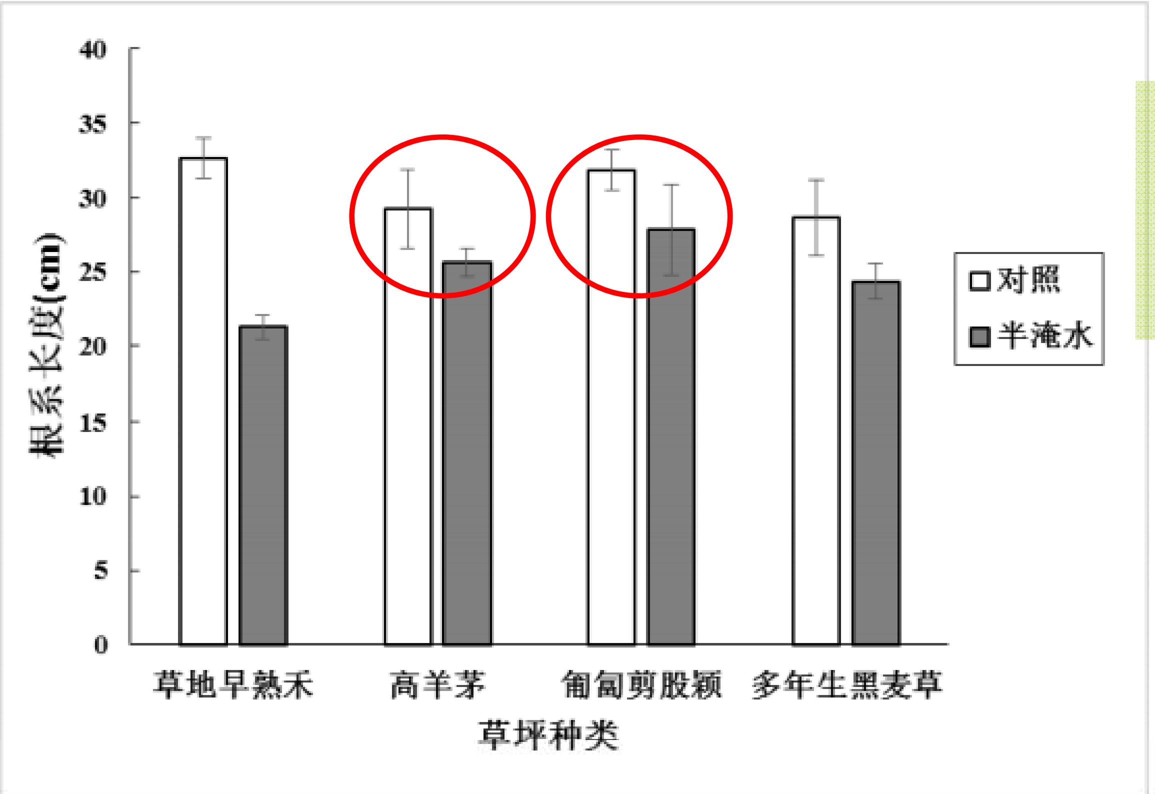

Tall fescue & perennial ryegrass

**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



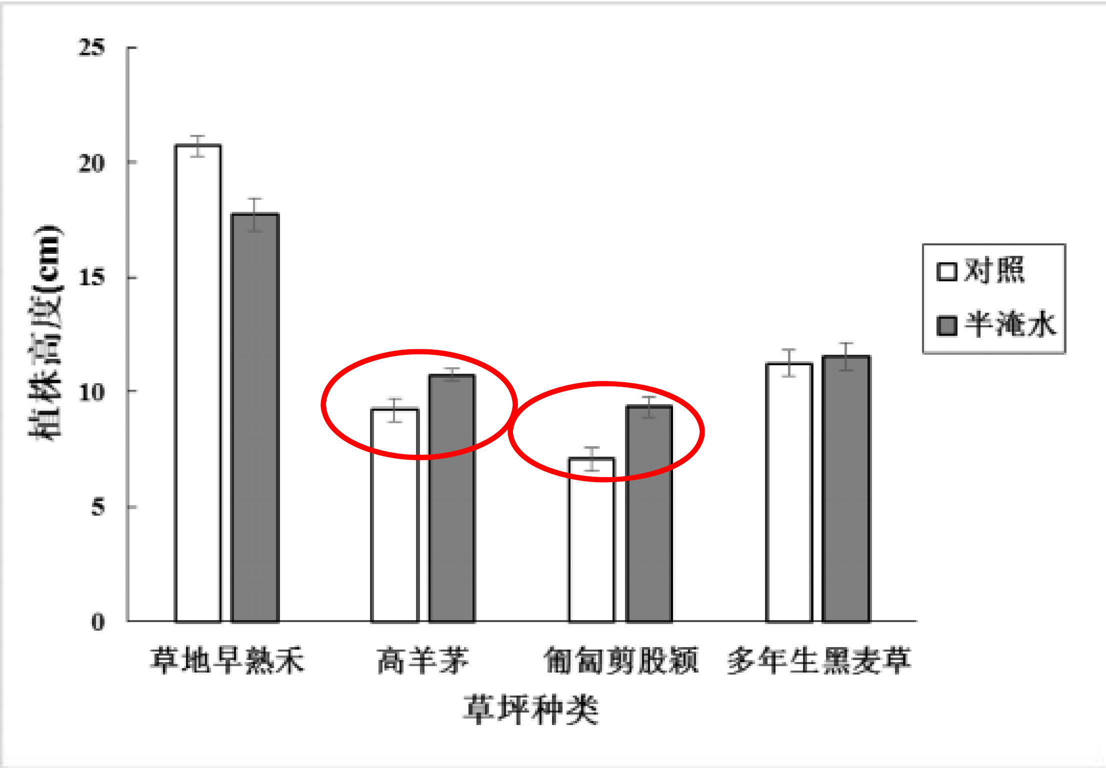

Tall fescue &
Creeping bentgrass

**图 2-3　不同淹水处理下各草种的根系长度**

**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**

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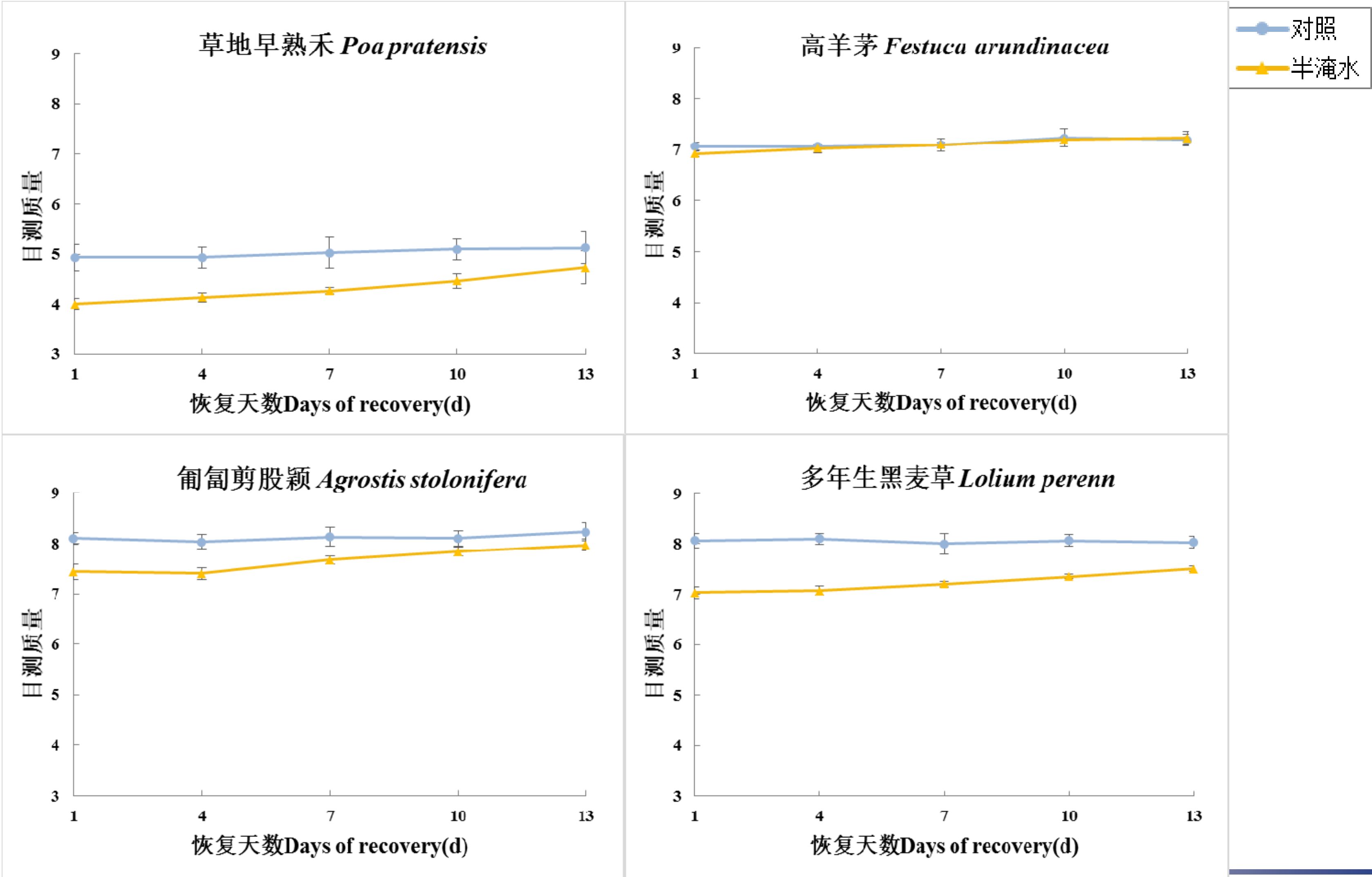
# Turf Quality Recovery

## 13 d recovery after waterlogged stress



# Conclusion

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

- Depth of flooding, and how long ?

# Tall fescue

- 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.


| Treatments | Turf quality | Leaf death rate/ % | Root length/ cm |
|---|---|---|---|
| CTL | 8.6 a | 3.30 c | 31.3 a |
| 0 mm | 7.8 b | 5.83 c | 28.3 ab |
| 40 mm | 6.4 c | 14.24 b | 25.3 ab |
| 80 mm | 3.2 d | 88.33 a | 22.8 b |

# Biomass

After 42 d

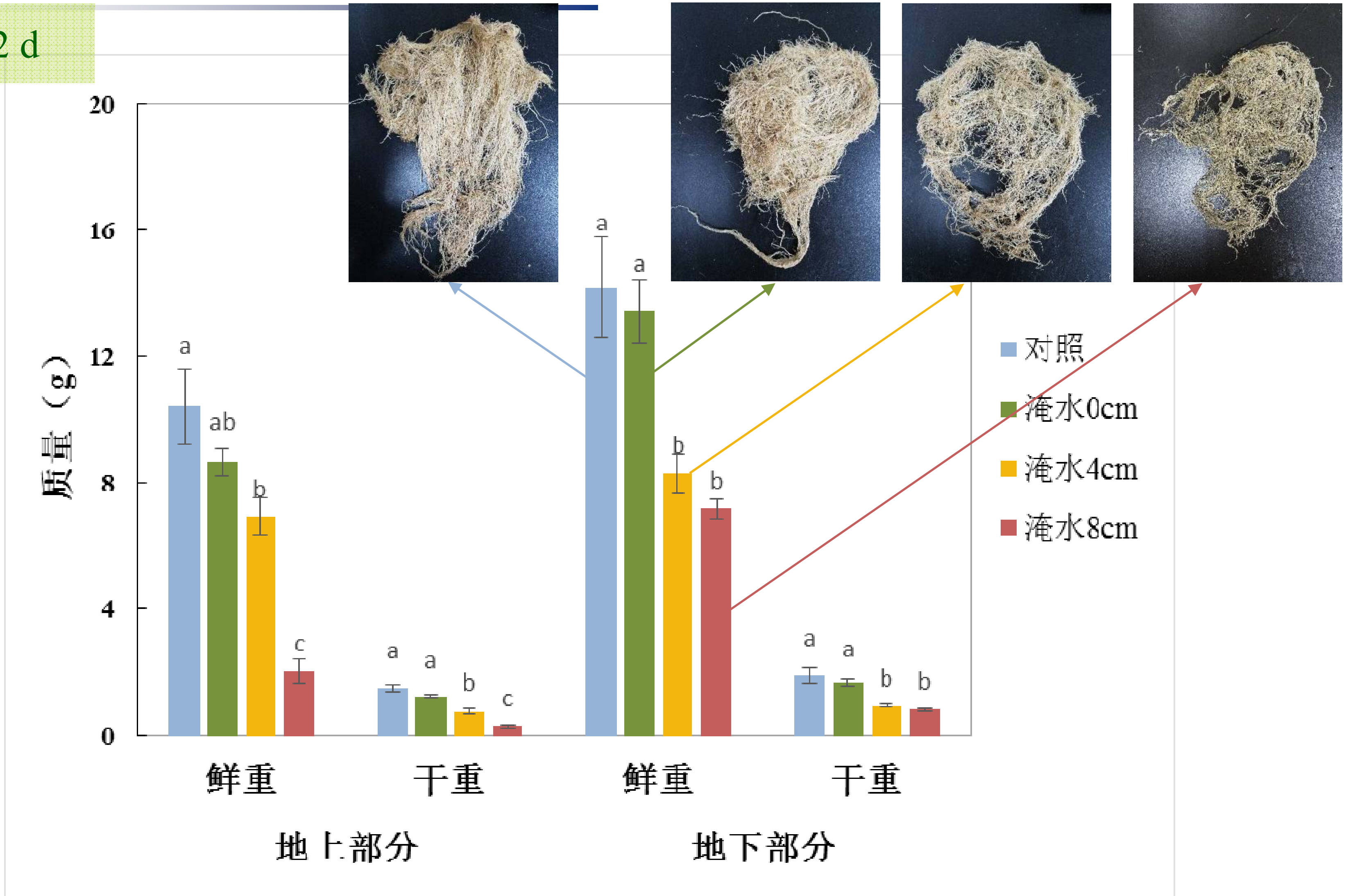



**图 3-5 不同淹水深度下高羊茅的生物量**

**Fig. 3-5 The biomass of Tall fescue under different flooding stress treatments**

# Chlorophyll Content

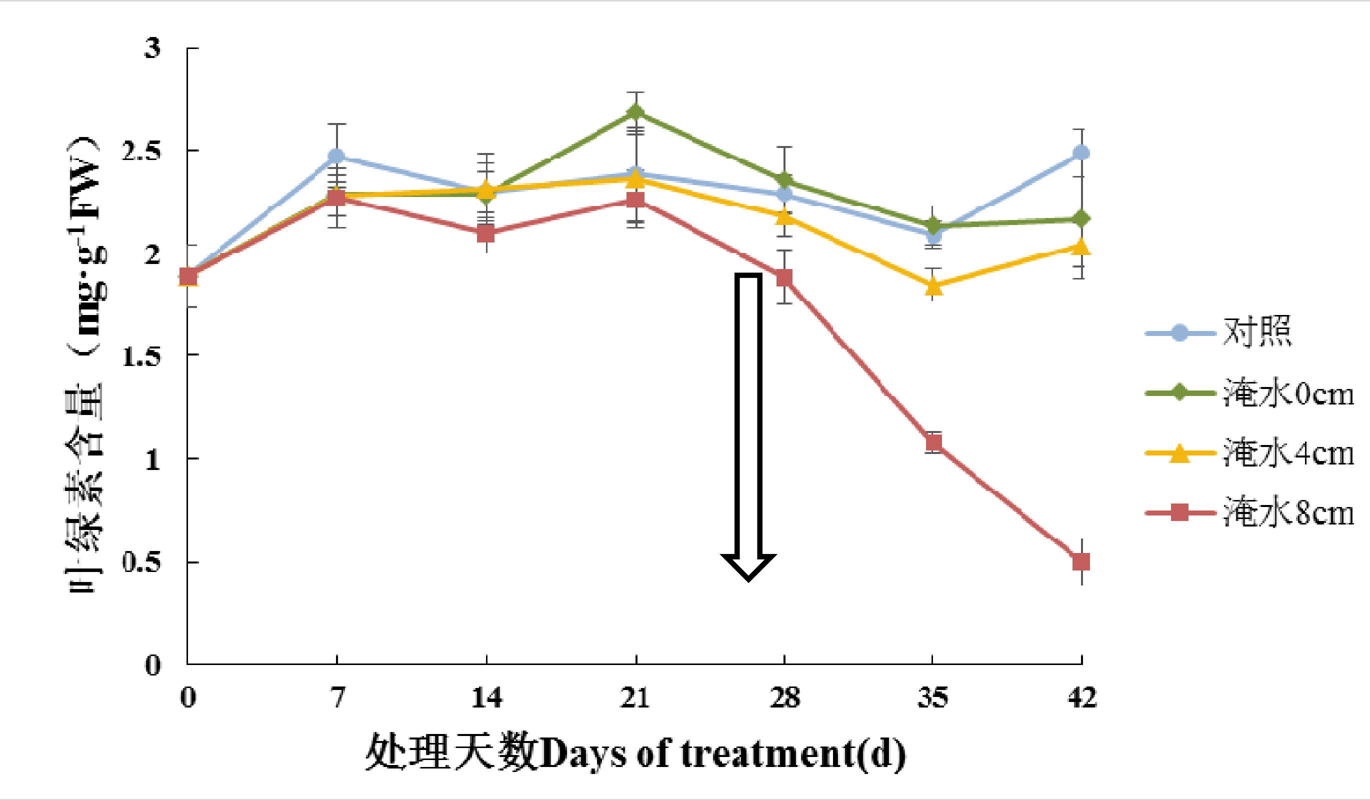



**图 3-1　不同淹水深度下高羊茅叶绿素含量的变化**

**Fig.3-1 The change of Chlorophyl content in leaves of Tall fescue under different flooding stress treatments**

# Souble sugar content

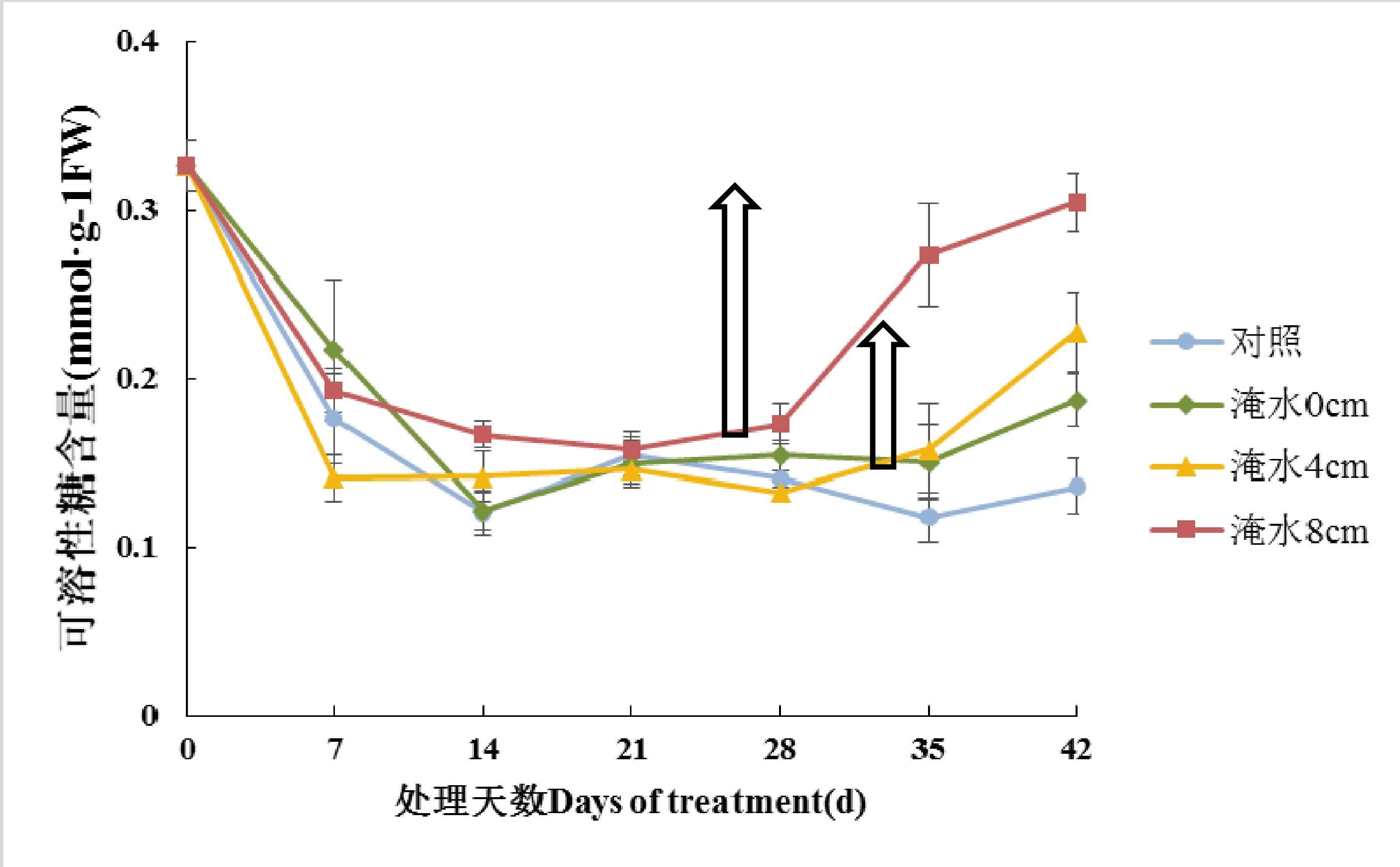



**图 3-3　不同淹水深度下高羊茅可溶性糖含量的变化**

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

# MDA content

(1) 淹水期间

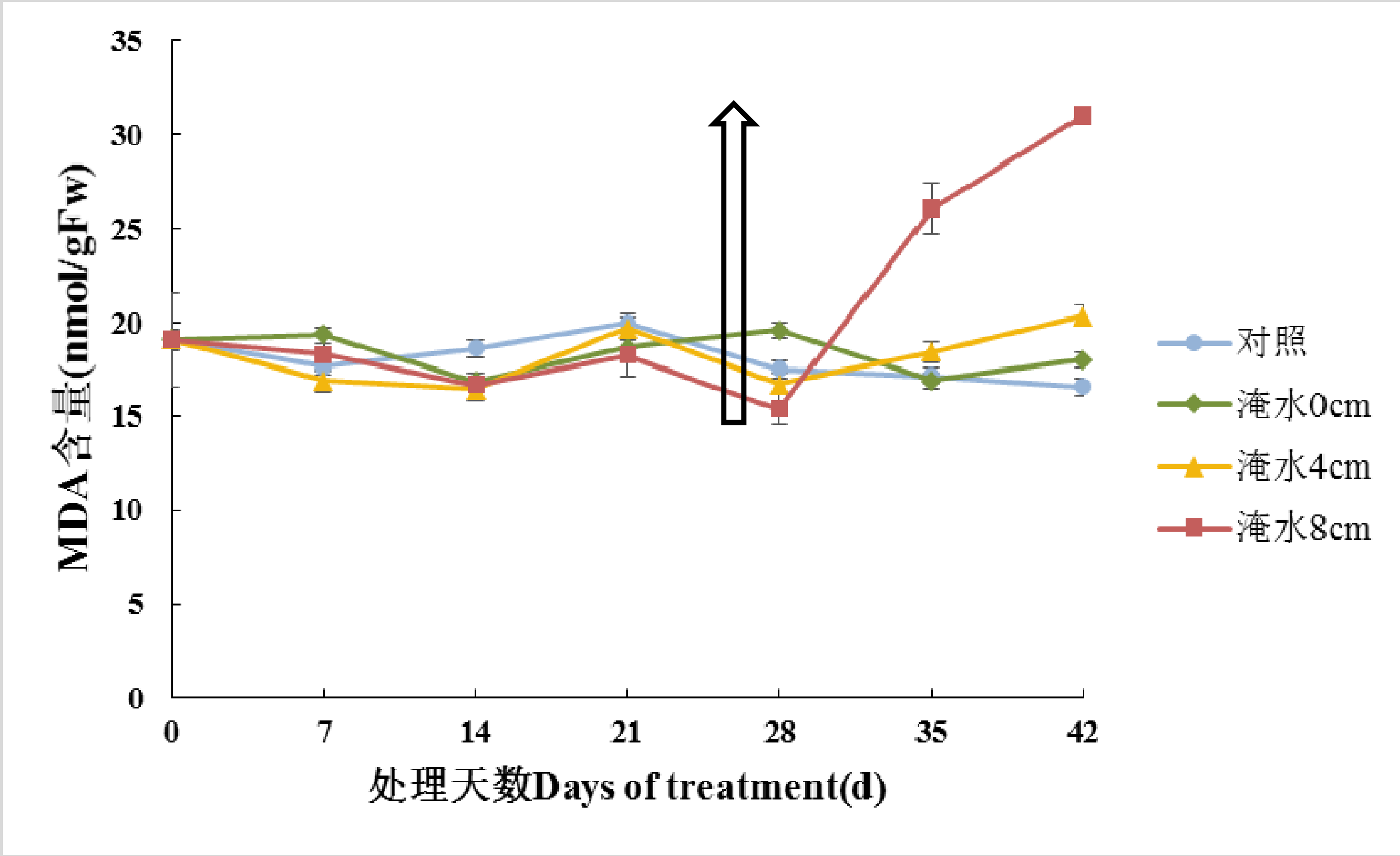



图 3-2　不同淹水深度下高羊茅丙二醛含量的变化

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

# Electrolyte leakage

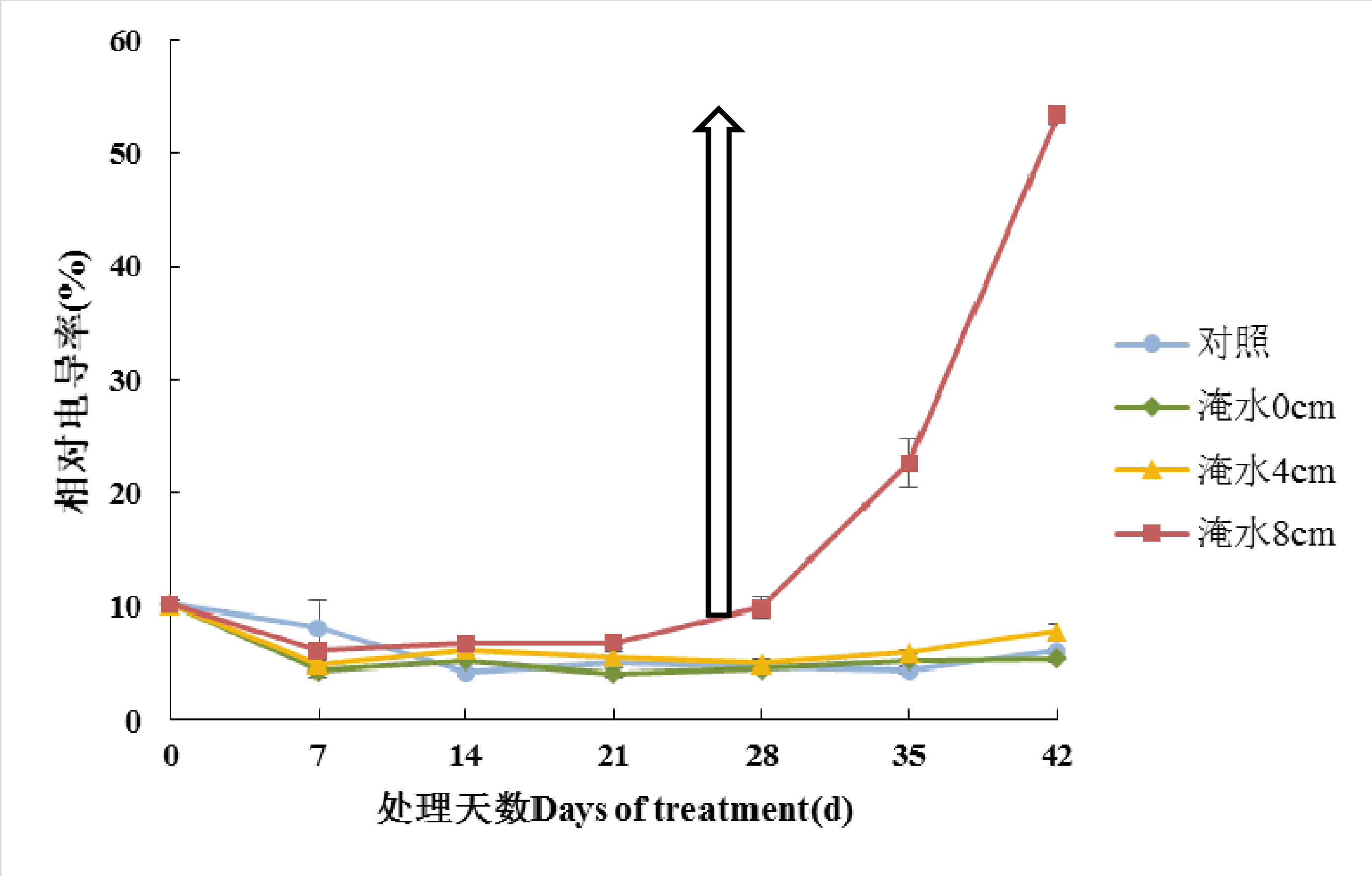
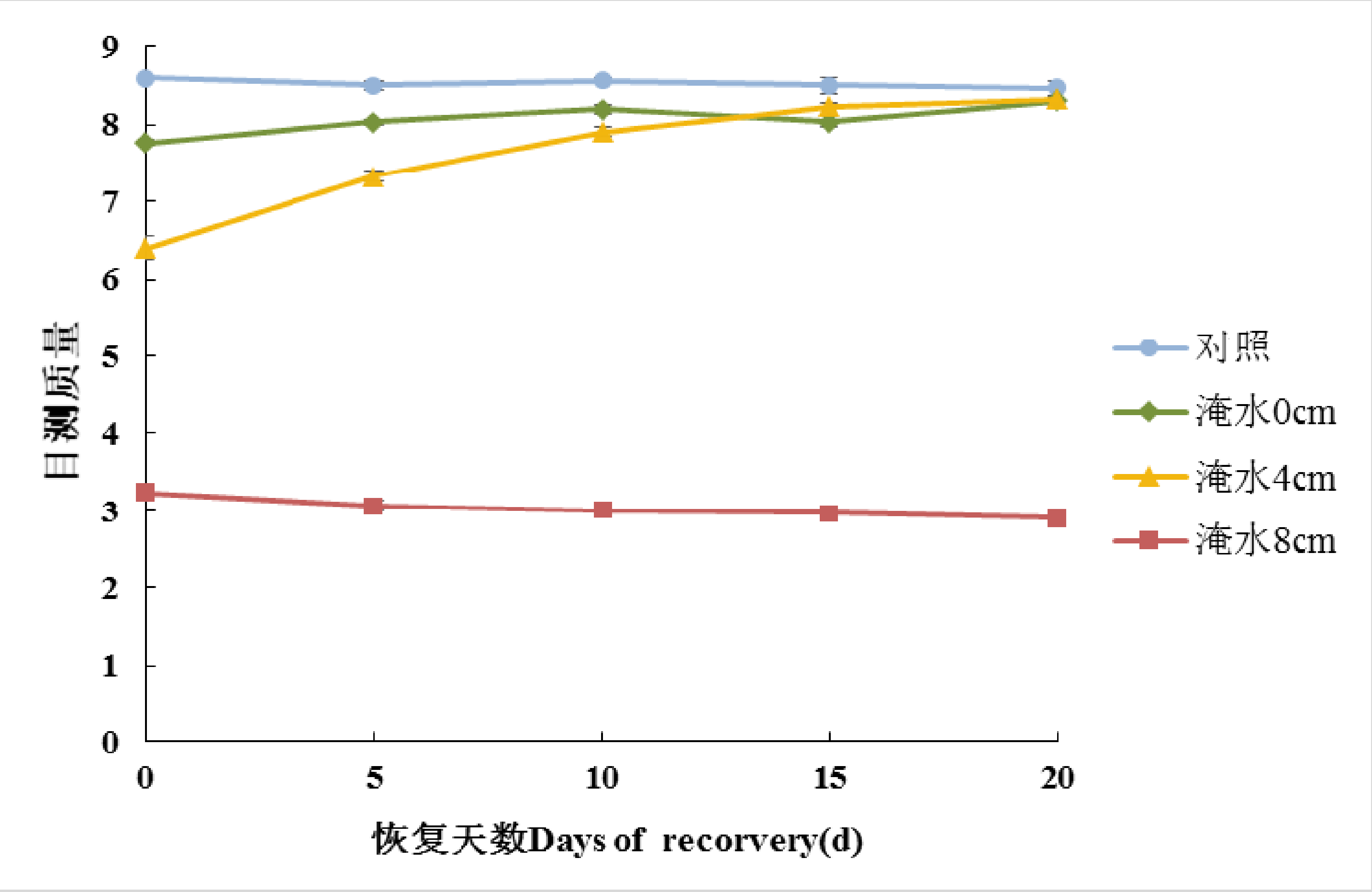



**图 3-4　不同淹水深度下高羊茅相对电导率的变化**

**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

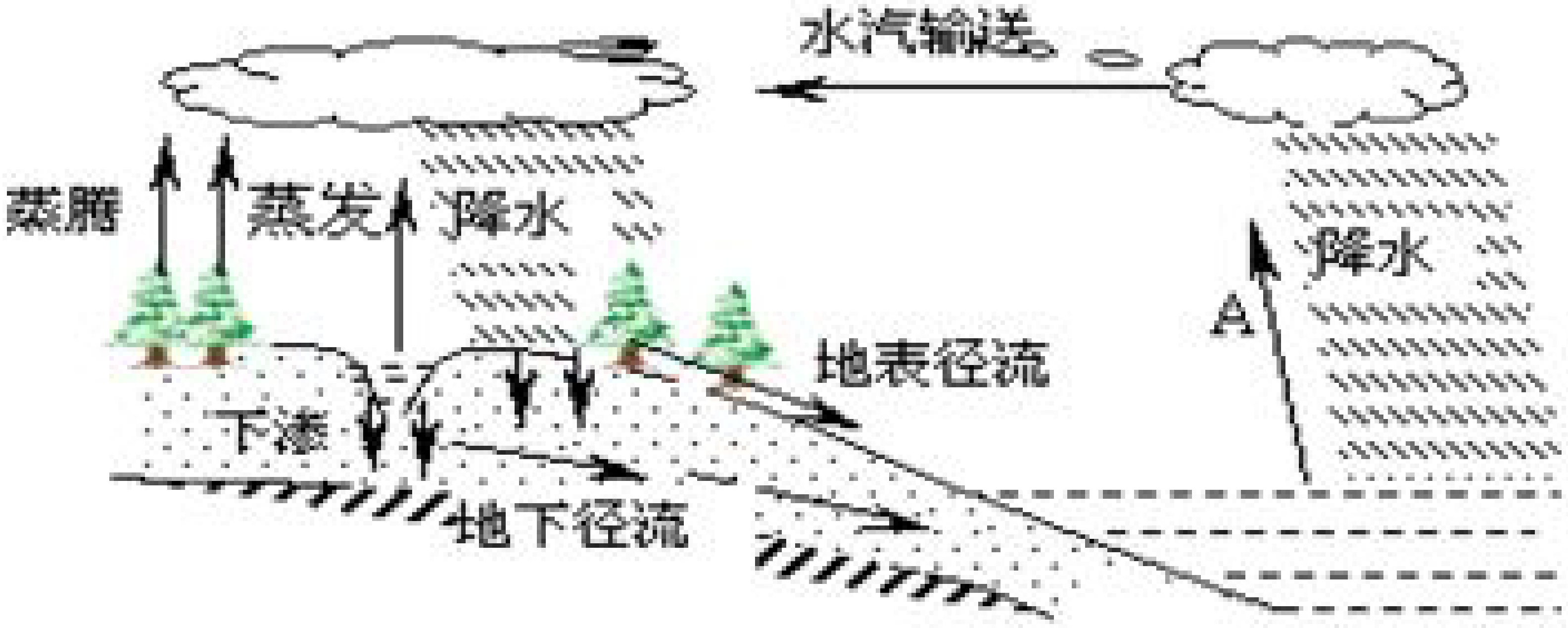


# Conclusion

- Tall fescue can tolerant 0 mm waterlogged stress for 42 d.
- Tall fescue can tolerant 40 mm waterlogged stress for 35 d.
- Tall fescue can tolerant 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.

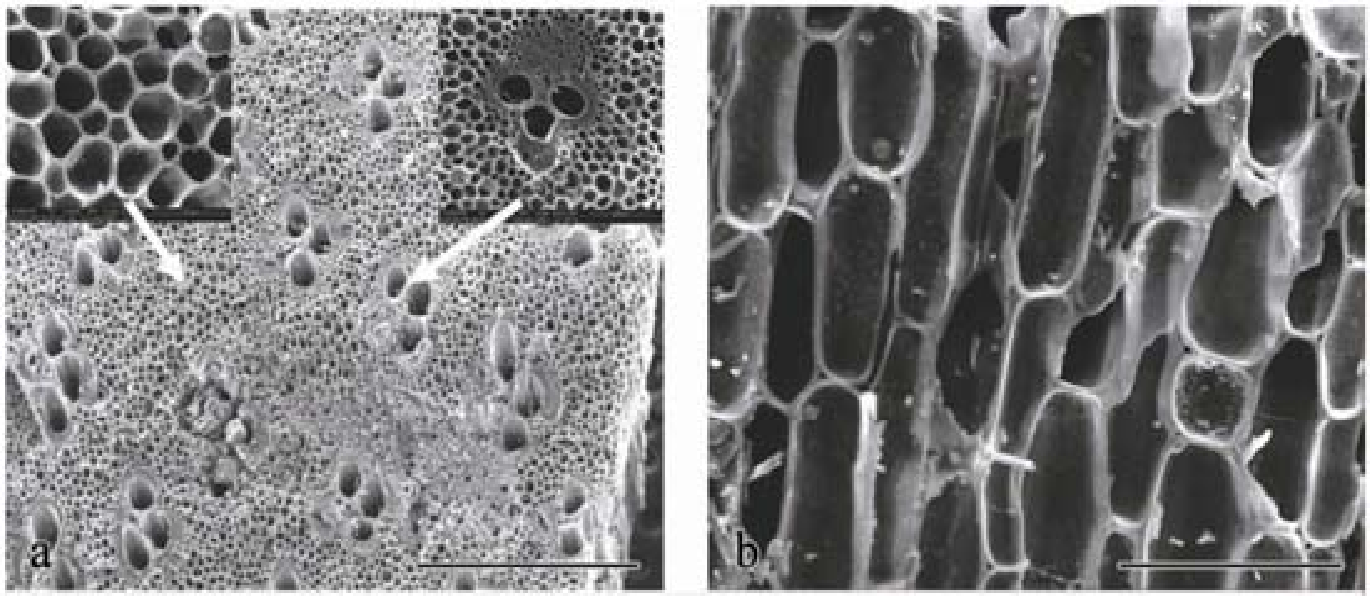
# II. Researches on water infiltration & retention

- 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

| Samples | ≧2mm | Particle size distribution (%) | | | | | Total sand 0.05-2mm | silt 0.002-0.05mm | clay ≦0.002 mm |
|---|---|---|---|---|---|---|---|---|---|
| | | Very coarse 1mm | Coarse 0.5mm | Medium .0.25mm | Fine 0.15mm | Very fine 0.05mm | | | |
| Biochar | 32±0.7a | 36±0.3c | 25±0.1h | 4±0.2g | 1±0.1g | 1±0.0f | 67±0.2h | 1.±0.0c | 0±0.0b |
| Coral#1 | 0±0.0d | 42±0.3b | 41±0.c | 14±0.1e | 0±0.0h | 0±0.0g | 99±0.0d | 1±0.1d | 0±0.0c |
| Coral #2 | 0±0.0d | 45±0.1a | 50±0.1b | 0±0.0h | 0±0.0h | 0±0.0g | 100±0.0a | 0±0.0g | 0.±0.0c |
| Vermiculite | 9±0.2c | 27±0.3d | 38±0.4e | 6±0.1f | 11±0.2a | 6±0.1b | 88±0.3f | 3±0.0b | 0±0.0c |
| CLITE | 0±0.0d | 24±0.1e | 34±0.1f | 30±0.2c | 6±0.1d | 5±0.1c | 99±0.1e | 1±0.0c | 0±0.0c |
| AXIS | 0±0.0d | 12±0.2c f | 58±0.5a | 24±0.6d | 4±0.2e | 1±0.0e | 99±0.2c | 0±0.0f | 0±0.0a |
| PROFILE | 0±0.0d | 0±0.0i | 39±0.5d | 58±0.7b | 2±0.2f | 1±0.1f | 100±0.2b | 0±0.0g | 0±0.0c |
| Peat moss | 13±0.1b | 10±0.2g | 21±0.2i | 30±0.1c | 9±0.1b | 15±0.1a | 83±0.1g | 4±0.1a | 0±0.0c |
| Sand | 0±0.0d | 2±0.0h | 29±0.1g | 59±0.4a | 8±0.4c | 2±0.1d | 99±0.1c | 1±0.0e | 0±0.0b |
| LSD | 3.8 | 0.4 | 0.5 | 0.6 | 0.3 | 0.1 | 0.3 | 0.1 | 0.1 |
| USGA | ≦10%( ≦3% 砾石) | | ≧60% | | ≦20% | ≦5% | | ≦5% | ≦3% |

# Tab.2-2 Physical & chemical properties of amendments

| Samples | hydraulic conductivity（cm/h） | porosity（%） | | | field capacity (%) | bulk density（g/cm³） | K + retent ion（mg/kg） | NO3- retention (mg/kg) | pH |
|---|---|---|---|---|---|---|---|---|---|
| | | Total | capillary | air-filled | | | | | |
| Biochar | 146±0.3a | 85±0.5a | 57±0.4b | 27±0.2c | 250±0.5b | 0.2±0.0g | 12353±4.6e | 942±3b | 9.7a |
| Coral#1 | 78±0.2f | 49±0.5dc | 40±0.2cd | 9±0.5f | 28±0.3g | 1.4±0.0c | 16970±8.4a | 24.1±0.4g | 8.0b |
| Coral #2 | 90±0.4e | 49±0.4cd | 36±0.5cd | 13±0.3e | 25±0.2h | 1.5±0.0b | 16585±9.4c | 23.8±0.5g | 7.9b |
| CLITE | 120±0.3c | 85±0.4a | 30±0.2d | 55±0.2a | 219±0.4c | 0.1±0.0h | 3566±6.4h | 231±0.7f | 7.6c |
| AXIS | 116±0.7d | 81±0.5ab | 46±0.3c | 35±0.6b | 108±0.5e | 0.4±0.1e | 16838±3.5b | 1539±3.5a | 7.6c |
| PROFILE | 123±0.2b | 67±0.3abc | 32±0.5d | 35±0.5b | 38±0.5f | 0.8±0.0d | 4222±4.7g | 317.0±1.5e | 6.5f |
| Vermiculite | 14±0.5h | 85±0.6a | 64±0.1b | 21±0.4d | 146±0.1d | 0.4±0.0e | 4389±5.6f | 345±2.6d | 6.3g |
| Peat moss | 10±0.2i | 83±0.5a | 74±0.3a | 9±0.3f | 286±0.6a | 0.3±0.0f | 14430±6.5d | 798±3.c | 6.7e |
| Sand | 73±0.3g | 42±0.2d | 19±0.1e | 23±0.2d | 12±0.1i | 1.6±0.1a | 2121±2.7i | 15.0±0.1h | 7.3d |
| LSD | 0.7 | 24.7 | 10.0 | 2.8 | 0.7 | 0.1 | 9.3 | 3.8 | 0.1 |

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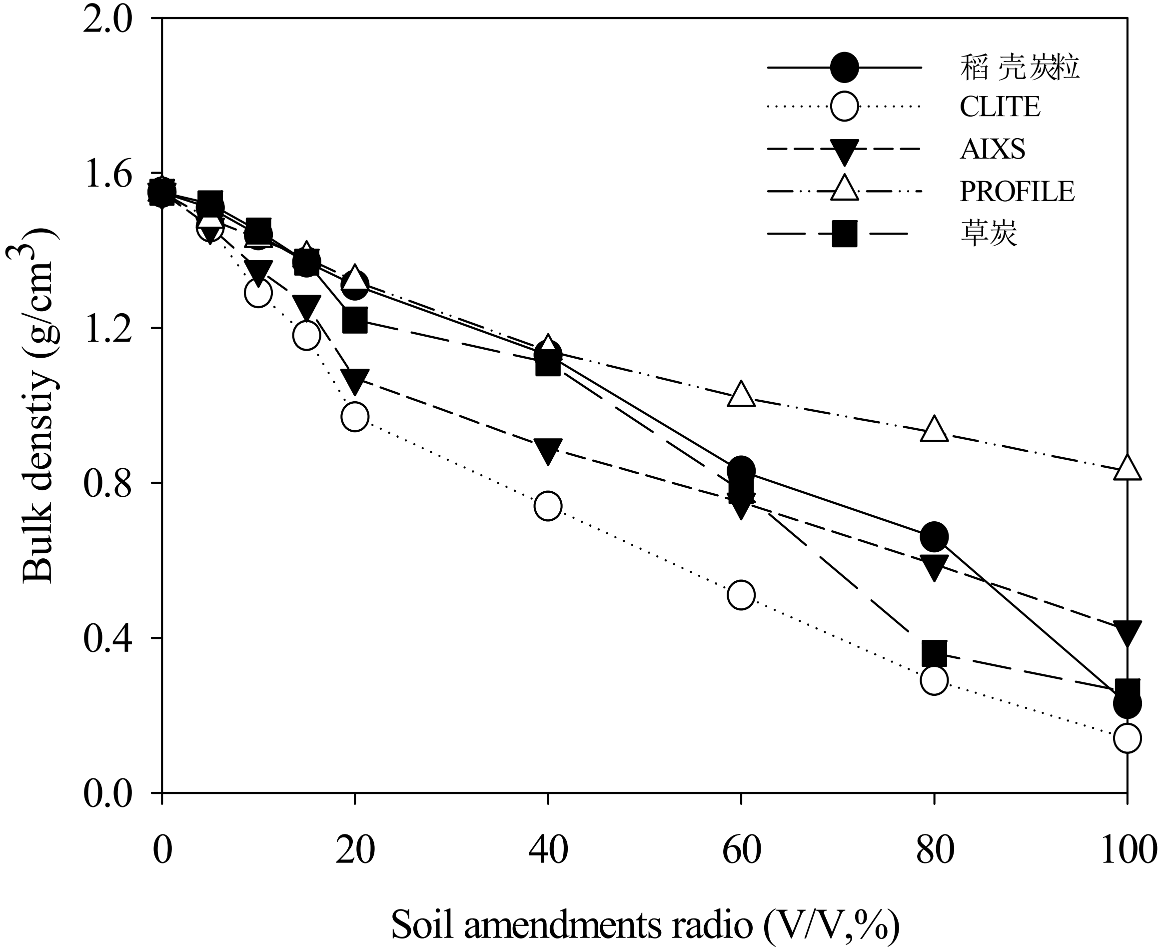
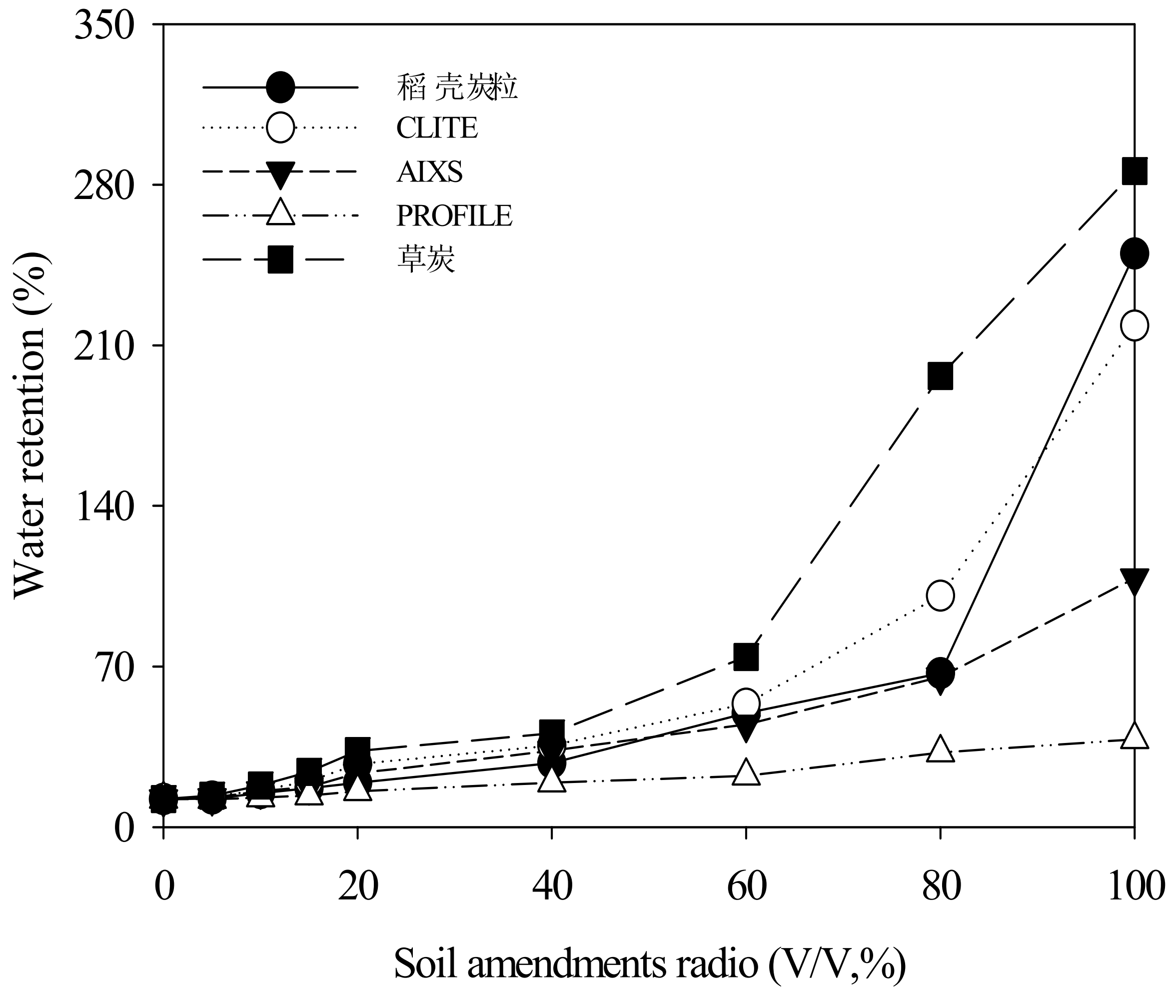
# Bulk density improvement

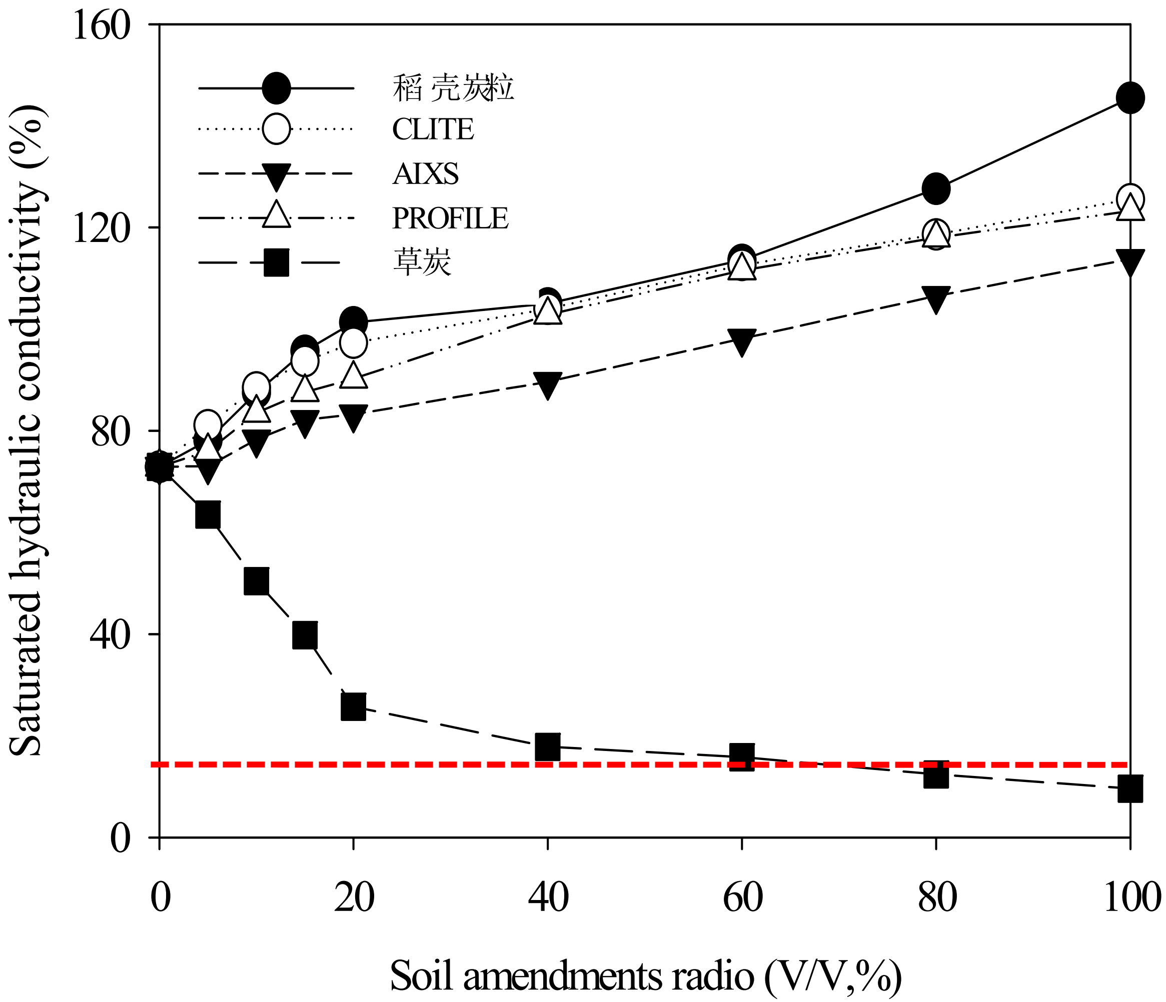


# Water retention improvement

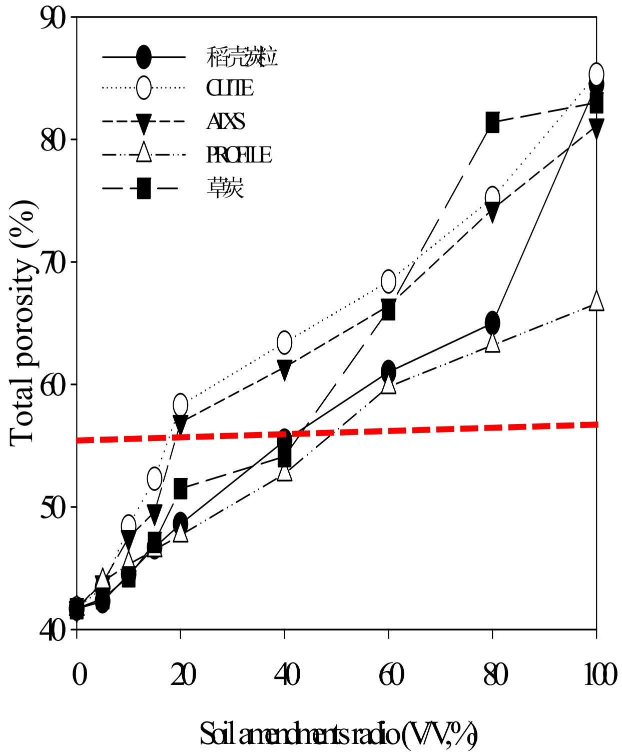


# Hydraulic conductivity improvement

USGA recommendation: ≥ 6 inches/hr(15 cm/h)

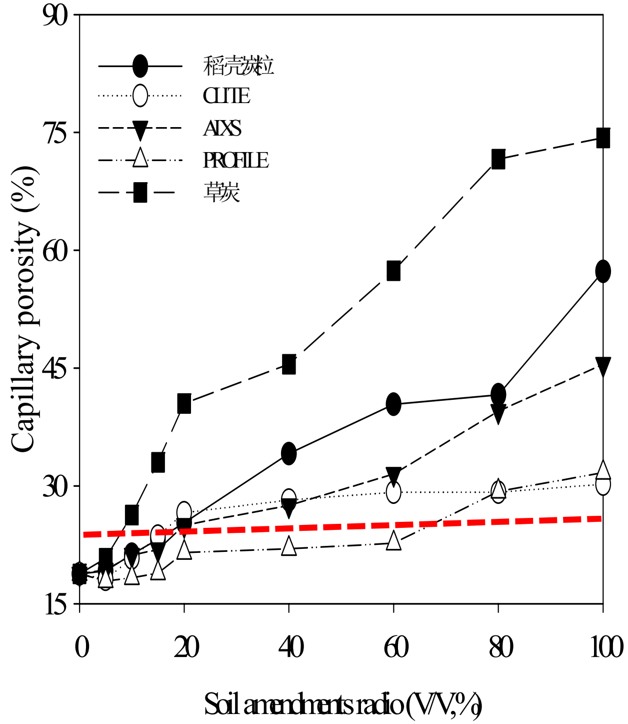


Total porosity



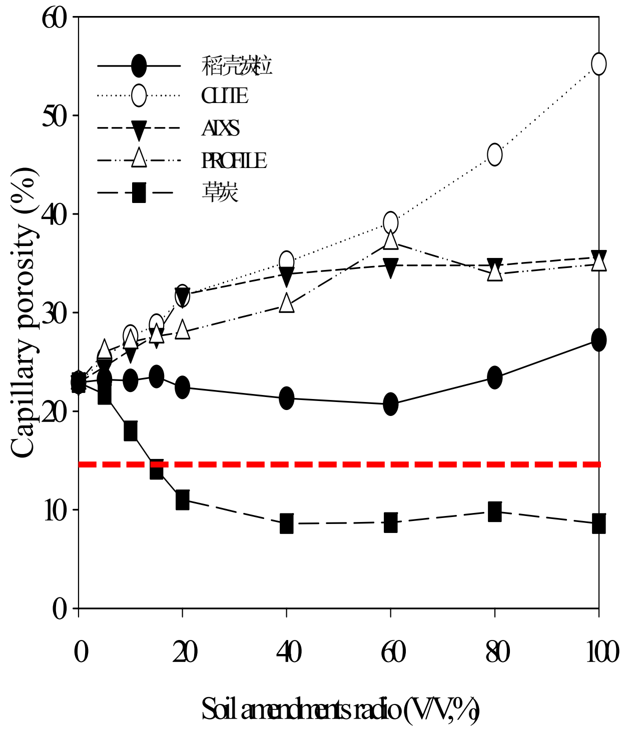

USGA recommendation:35%-55%

Capillary porosity



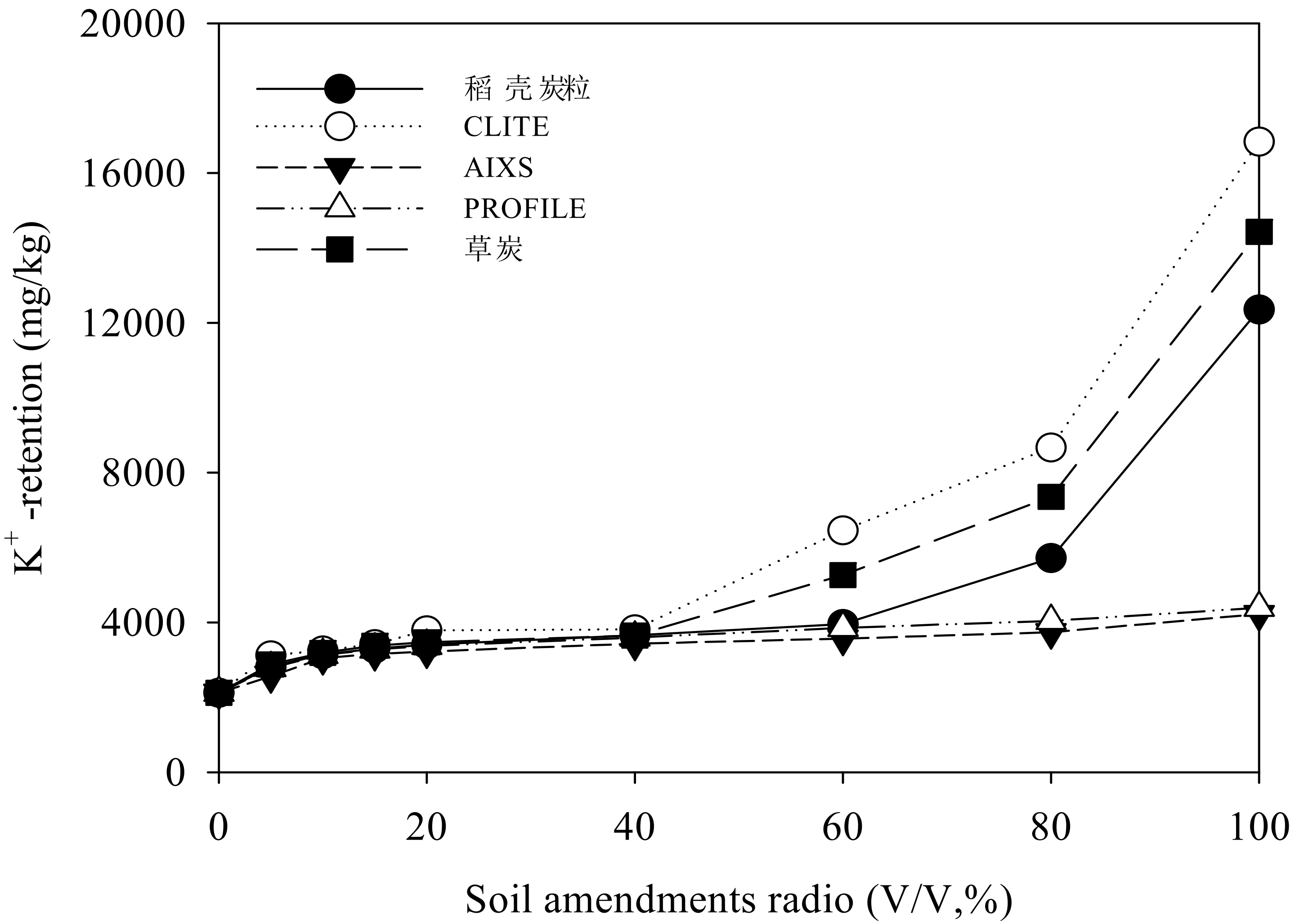

USGA recommendation:15%-25%

Air-filled porosity

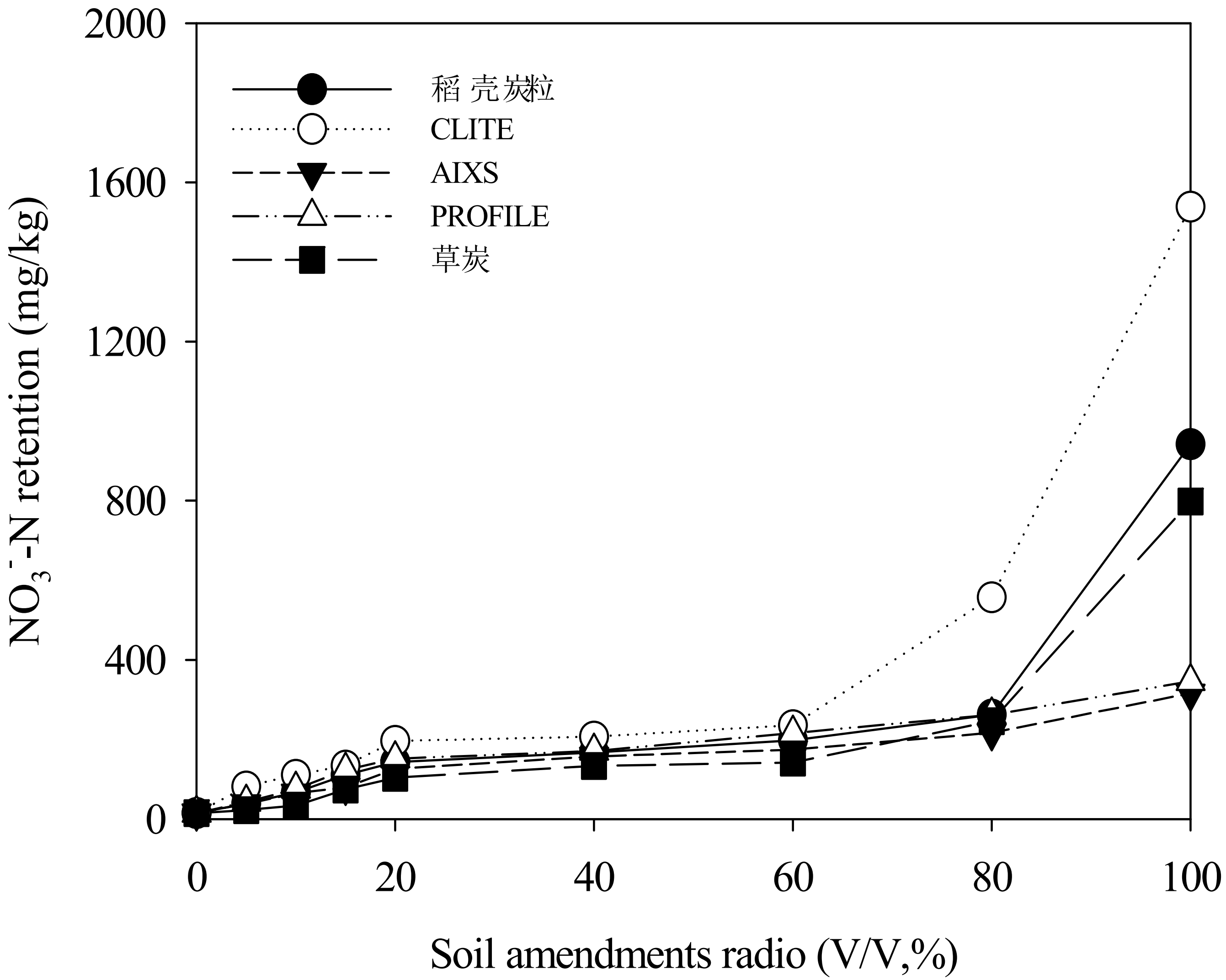



USGA recommendation:15%-30%

# $K^+$ retention improvement



# $NO_3^-$ retention improvement

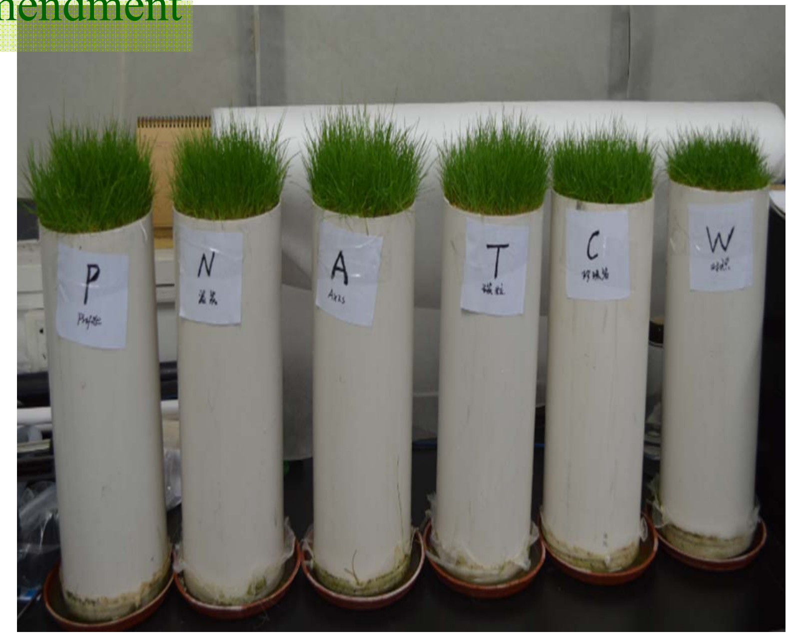


# Conclusion

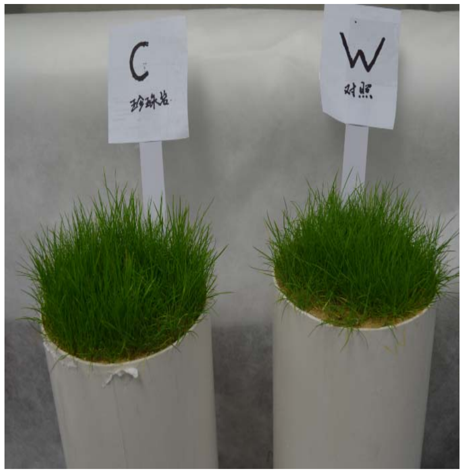
- Improvements of bulk density, water retention, nutrients retention…
- Biochar ≤15%
- AXIS ≤15%
- CLITE ≤15%
- Peat moss ≤10%
- PROFILE ≤20%

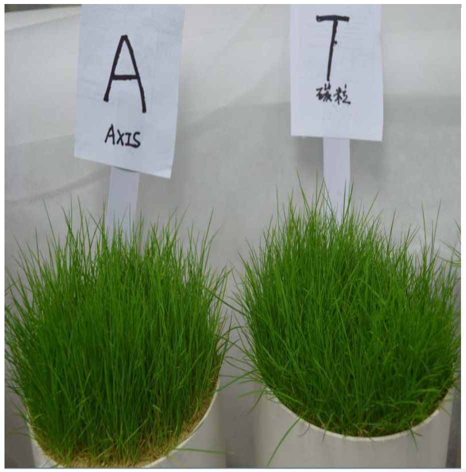
# Effects on bentgrass establishment

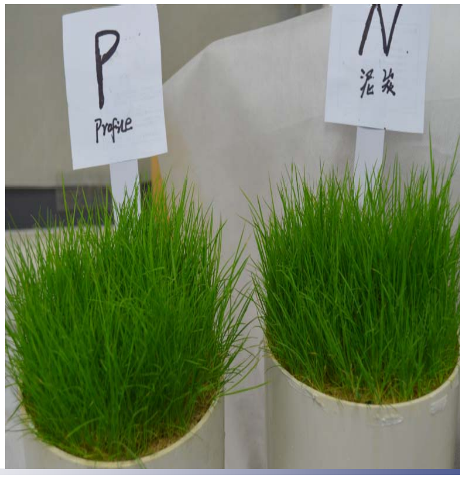
10% amendment







# Leaf emergence of creeping bentgrass

| Amendments | Leaf age | | | |
|---|---|---|---|---|
| | 10d | 17d | 24d | 31d |
| PROFILE | 1.5a | 2.8a | 4.2a | 4.5a |
| AXIS | 1.3bc | 2.6bc | 4.0bc | 4.2b |
| Biochar | 1.3bc | 2.6bc | 3.9bc | 4.0c |
| CLITE | 1.2c | 2.6c | 3.7cd | 3.8cd |
| Peat moss | 1.3b | 2.7b | 4.0b | 4.5a |
| Sand | 1.2c | 2.5c | 3.6d | 3.7d |
| LSD0.05 | 0.1 | 0.1 | 0.2 | 0.2 |

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# Tillers/plant of creeping bentgrass

| Amendment | Tillers/plant | | |
|---|---|---|---|
| | 17d | 24d | 31d |
| PROFILE | 1.5a | 2.6a | 2.8a |
| AXIS | 1.4bc | 2.2c | 2.6b |
| Biochar | 1.3bcd | 2.2c | 2.6b |
| CLITE | 1.3cd | 2.0d | 2.3c |
| Peat moss | 1.4ab | 2.5b | 2.8a |
| Sand | 1.2d | 1.7e | 1.8d |
| LSD0.05 | 0.1 | 0.1 | 0.1 |

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# Vertical growth rate of creeping bentgrass

| Amendment | Growth rate (mm/d) | | | |
|---|---|---|---|---|
| | 10d | 17d | 24d | 31d |
| PROFILE | 1.93a | 1.83a | 3.08a | 3.26a |
| AXIS | 1.68bc | 1.60b | 2.43b | 3.19a |
| Biochar | 1.55cd | 1.43bc | 1.98c | 2.75b |
| CLITE | 1.54d | 1.34c | 1.99c | 2.20c |
| Peat moss | 1.69b | 1.84a | 3.07a | 3.20a |
| Sand | 1.54d | 1.28c | 1.38d | 1.53d |
| LSD0.05 | 0.14 | 0.24 | 0.27 | 0.22 |

# Turf coverage of creeping bentgrass

| Amendment | Turf coverage (%) | | | |
|---|---|---|---|---|
| | 10d | 17d | 24d | 31d |
| PROFILE | 25.6a | 35.0a | 71.4a | 91.4a |
| AXIS | 22.8b | 29.6b | 62.5d | 73.8b |
| Biochar | 19.4c | 25.1c | 53.7c | 69.2b |
| CLITE | 19.0c | 24.6c | 52.2c | 68.8b |
| Peat moss | 25.3ab | 33.8b | 69.4a | 88.1a |
| Sand | 16.8c | 20.6d | 41.5d | 52.5c |
| LSD0.05 | 2.5 | 3.2 | 4.7 | 5.5 |

# Plant biomass of creeping bentgrass

| Amendment | Biomass (mg/plant) | | | Root length (cm) |
|---|---|---|---|---|
| | Total | Shoot | Root | |
| PROFILE | 6.6a | 5.1a | 1.5a | 4.5b |
| AXIS | 5.3b | 4.4bc | 0.9c | 4.5b |
| Biochar | 5.1b | 4.3c | 0.8d | 4.3b |
| CLITE | 4.0c | 2.9d | 1.1b | 5.2a |
| Peat Moss | 5.3b | 4.6b | 0.7d | 3.1c |
| Sand | 2.3d | 1.9e | 0.4e | 2.7d |
| LSD0.05 | 0.2 | 0.2 | 0.1 | 0.4 |

# Conclusion

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

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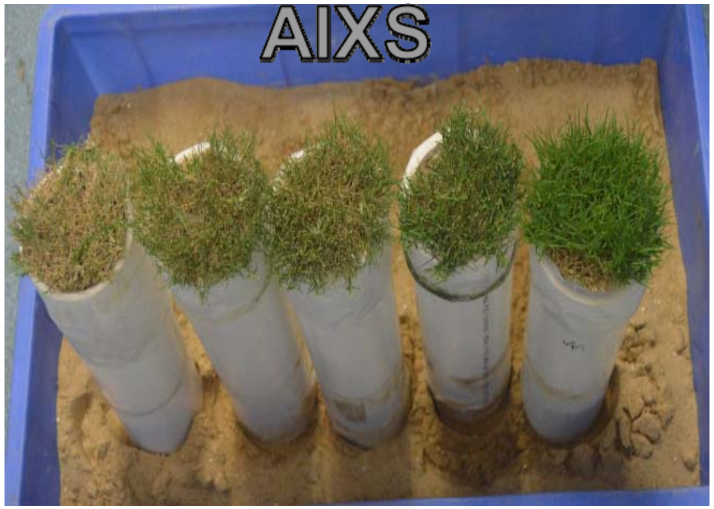
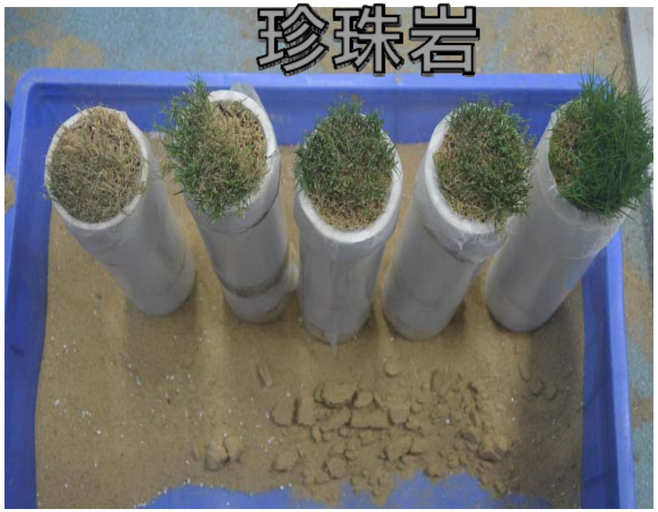
# Effects on drought tolerance

25d of drought stress

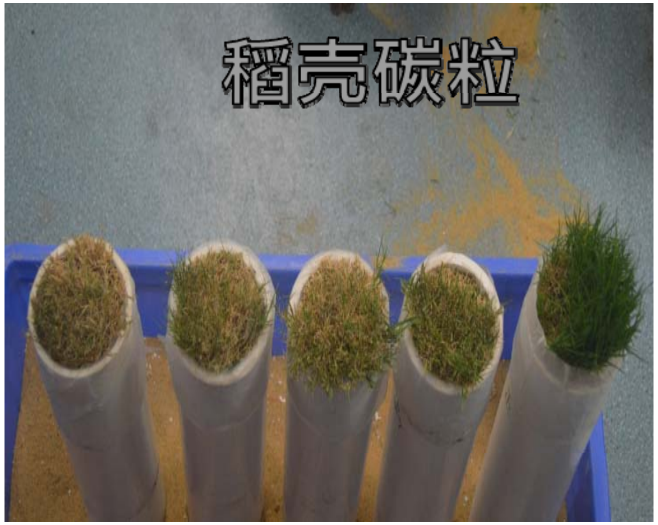



0%　5%　10%　15%　CTL




0%　5%　10%　15%　CTL


0%　5%　10%　15%　CTL




0%　5%　10%　15%　CTL

# Growth rate under drought stress

| Treatments | Ratio% | Growth rate（g/5d） | | |
|---|---|---|---|---|
| | | 0d | 5d | 10d |
| Biochar | 5 | 1.0def | 0.7fh | 0.1f |
| | 10 | 1.0def | 0.9e | 0.2f |
| | 15 | 1.0cdef | 0.6fh | 0.2f |
| AXIS | 5 | 1.0ef | 1.0de | 0.6ab |
| | 10 | 0.9f | 1.2bcd | 0.6ab |
| | 15 | 1.2bcdef | 1.2bcd | 0.7a |
| CLITE | 5 | 1.0cdef | 1.2abcd | 0.5cd |
| | 10 | 1.2bc | 1.4b | 0.6bc |
| | 15 | 1.3b | 0.9ef | 0.4de |
| PROFILE | 5 | 1.2bcde | 1.2bcd | 0.4e |
| | 10 | 1.2bcd | 1.2bcd | 0.5de |
| | 15 | 1.6a | 1.3bc | 0.5cd |
| Sand | | 1.1bcdef | 0.4h | 0.0h |

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# Phytosynthetic efficiency under drought stress

| Amendment | Ratio% | Phytosyntheticefficiency (FV/FM) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0d | 5d | 10d | 15d | 20d | 25d |
| Biochar | 5 | 0.75a | 0.73b | 0.72c | 0.66d | 0.64bcd | 0.44d |
| | 10 | 0.75a | 0.73b | 0.72cb | 0.67bcd | 0.65abcd | 0.46c |
| | 15 | 0.75a | 0.73b | 0.72cb | 0.66cd | 0.64bcd | 0.44c |
| AXIS | 5 | 0.75a | 0.73b | 0.71c | 0.68abc | 0.65abcd | 0.45e |
| | 10 | 0.75a | 0.73b | 0.71c | 0.68ab | 0.66abcd | 0.51d |
| | 15 | 0.75a | 0.74b | 0.71c | 0.69a | 0.67ab | 0.57ab |
| CLITE | 5 | 0.75a | 0.73b | 0.72abc | 0.68ab | 0.66abcd | 0.54b |
| | 10 | 0.75a | 0.75ab | 0.73a | 0.68ab | 0.66abcd | 0.63a |
| | 15 | 0.75a | 0.74ab | 0.71c | 0.67bcd | 0.67ab | 0.61ab |
| PROFILE | 5 | 0.75a | 0.73b | 0.71c | 0.67bcd | 0.66abc | 0.55ab |
| | 10 | 0.75a | 0.74b | 0.71c | 0.68abc | 0.67ab | 0.59ab |
| | 15 | 0.75a | 0.75ab | 0.72abc | 0.69a | 0.68ab | 0.60ab |
| Sand | | 0.75a | 0.74ab | 0.71c | 0.63e | 0.58d | 0.22e |

# Leaf electrolyte leakage under drought stress

| Amendment | Ratio% | Leaf electrolyte leakage （%） | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0d | 5d | 10d | 15d | 20d | 25d |
| Biochar | 5 | 11.4a | 14.7abc | 26.0db | 41.8bc | 51.4b | 61.9b |
| | 10 | 11.7a | 13.6bcd | 22.7cde | 38.1bcd | 47.6bcd | 51.4d |
| | 15 | 11.4a | 14.6abc | 25.5bcd | 43.2b | 50.4b | 56.7c |
| AXIS | 5 | 11.7a | 12.7cd | 25.4bcd | 36.4bcd | 44.4bcd | 50.2de |
| | 10 | 11.8a | 13.0cd | 22.6cde | 32.9e | 41.8bcd | 46.3fhi |
| | 15 | 11.3a | 12.9cd | 20.4e | 30.5de | 38.8cde | 43.4i |
| CLITE | 5 | 11.5a | 13.6bcd | 25.5bcd | 36.7bcd | 41.3bcde | 49.2def |
| | 10 | 11.6a | 13.7bcd | 24.8bcde | 33.0d | 37.1de | 43.5i |
| | 15 | 11.8a | 15.6ab | 28.8ab | 34.9bcd | 41.4e | 45.7hi |
| PROFILE | 5 | 11.5a | 14.0bcd | 25.2bcd | 36.8bcd | 48.8bc | 55.6c |
| | 10 | 11.6a | 13.0cd | 24.2bcde | 34.3cd | 46.1bcd | 50.8d |
| | 15 | 11.5a | 12.8cd | 21.0de | 31.1de | 42.1bcd | 47.5efh |
| Sand | | 11.4a | 16.2a | 31.4a | 52.2a | 62.9a | 82.1a |

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# Leaf chlorophyll content under drought stress

| Amendment | Ratio % | Leaf chlorophyll content （mg/gDW） | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0d | 5d | 10d | 15d | 20d | 25d |
| Biochar | 5 | 4.4a | 4.1a | 3.3bcd | 2.8bcd | 1.6c | 1.ode |
| | 10 | 4.4a | 4.4a | 3.6abc | 3.2bc | 2.2ab | 1.4bc |
| | 15 | 4.4a | 4.3a | 3.5abcd | 3.1bc | 1.9bc | 1.1de |
| AXIS | 5 | 4.2a | 4.2a | 2.9de | 2.8bcd | 2.2ab | 1.5abc |
| | 10 | 4.4a | 4.2a | 3.8cde | 3.5ab | 2.3ab | 1.7a |
| | 15 | 4.4a | 4.3a | 4.0ab | 3.5ab | 2.5a | 1.8a |
| CLITE | 5 | 4.2a | 4.2a | 3.0cde | 2.8bcd | 2.1ab | 1.6a |
| | 10 | 4.2a | 4.3a | 3.4bcde | 3.1bc | 2.6a | 1.9a |
| | 15 | 4.4a | 4.3a | 3.5abc | 2.9bcd | 2.2ab | 1.7a |
| PROFILE | 5 | 4.3a | 4.2a | 3.6abc | 2.8bcd | 2.2ab | 1.1cd |
| | 10 | 4.4a | 4.2a | 3.8abc | 3.1bc | 2.3ab | 1.2bcd |
| | 15 | 4.5a | 4.3a | 4.1abc | 3.2bc | 2.3ab | 1.3bcd |
| Sand | | 4.3a | 3.8a | 2.4e | 2.1e | 0.9d | 0.7f |

# Leaf relative water content under drought stress

| Amendment | Ratio % | Leaf relative water content（%） | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0d | 5d | 10d | 15d | 20d | 25d |
| Biochar | 5 | 93.8a | 92.2a | 80.9bc | 62.2d | 46.4f | 13.8de |
| | 10 | 93.1a | 92.4a | 85.9abc | 68.4c | 52.9de | 22.1de |
| | 15 | 93.6a | 91.8ab | 85.9ab | 68.4c | 51.5e | 19.4de |
| AXIS | 5 | 93.7a | 92.7a | 83.6abc | 69.1c | 56.2c | 25.7cd |
| | 10 | 94.6a | 92.8a | 85.2abc | 75.8da | 63.1b | 33.5bc |
| | 15 | 93.4a | 93.7a | 86.5a | 77.2a | 66.5a | 34.5bc |
| CLITE | 5 | 93.7a | 92.5a | 82.6c | 67.4c | 56.9c | 29.4de |
| | 10 | 93.4a | 92.4a | 84.2abc | 75.3da | 66.7a | 44.5a |
| | 15 | 93.8a | 93.2a | 84.7abc | 76.9a | 65.1ab | 43.6ab |
| PROFILE | 5 | 93.9a | 91.7ab | 82.6bc | 69.0c | 52.9de | 22.5de |
| | 10 | 93.1a | 92.0a | 85.2abc | 74.0b | 55.6cd | 28.3cd |
| | 15 | 93.4a | 93.2a | 86.0ab | 77.4a | 58.1c | 34.1bc |
| Sand | | 93.6a | 88.9b | 77.9d | 50.6e | 38.7h | 14.9e |

# Soil water content, root biomass, root activity

| Amendment | Ratio % | Root activity (%) | Root biomass (g) | Soil water content(%) |
|---|---|---|---|---|
| Bichar | 5 | 69.8bc | 0.6g | 2.4ab |
| | 10 | 60.5ef | 0.7fg | 2.7ab |
| | 15 | 63de | 0.6fg | 2.9a |
| AXIS | 5 | 69.5bc | 0.7fg | 0.6f |
| | 10 | 54.8gh | 1.0abcd | 1.2de |
| | 15 | 53.1ghi | 1.0abc | 1.3cd |
| CLITE | 5 | 67.9cd | 0.8ef | 0.8ef |
| | 10 | 48.3i | 1.1a | 1.7b |
| | 15 | 50.2hi | 1.1ab | 2.3c |
| PROFILE | 5 | 67.5cd | 0.8def | 0.5f |
| | 10 | 56.1fg | 0.9cde | 0.8ef |
| | 15 | 51.6ghi | 0.9cde | 1.2ed |
| Sand | | 75.5a | 0.4h | 0.5f |

# Conclusion

- All amendments improved turfgrass drought tolerance.
- Effects order: CLITE ＞ AXIS ＞ PROFILE ＞ Biochar

# Effects on nutrients leaching

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# Effects on N leaching

| Amendment | Application N ( mg/m²) | Leaching solution | | | | | |
|---|---|---|---|---|---|---|---|
| | | Total N | | NH4+-N | | NO3-N | |
| | | mg/L | Lose % | mg/L | Lose % | mg/L | Lose % |
| CLITE | 2386.4 | 2.24b | 21.4b | 0.28d | 2.7d | 1.94c | 18.4c |
| Peat | 2386.4 | 2.31b | 22.0b | 0.30cd | 2.9cd | 1.95c | 18.6c |
| Biochar | 2386.4 | 2.43b | 23.2b | 0.31c | 2.9c | 2.09bc | 19.9bc |
| PROFILE | 2386.4 | 2.60b | 24.8b | 0.40b | 3.8b | 2.13b | 20.2b |
| AXIS | 2386.4 | 2.63b | 25.1b | 0.41ab | 3.9ab | 2.16b | 20.6b |
| Sand | 2386.4 | 4.04a | 38.4a | 0.43a | 4.1a | 3.23a | 30.8a |
| LSD0.05 | | 0.43 | 4.2 | 0.02 | 0.2 | 0.15 | 1.5 |

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# Effects on K leaching

| Amendment | Application K（$mg/m^2$） | Leaching solution | |
|---|---|---|---|
| | | $K^+$（mg/L） | Loss (%) |
| CLITE | 46.8 | 2.97c | 25.4bc |
| Peat | 46.8 | 2.84bc | 24.3c |
| Biochar | 46.8 | 3.01bc | 25.7bc |
| PROFILE | 46.8 | 3.23bc | 27.6bc |
| AXIS | 46.8 | 3.41b | 29.2b |
| Sand | 46.8 | 5.24a | 44.8a |
| LSD0.05 | | 0.5 | 4.1 |

# Conclusion

- All amendments decrased nutrients leaching.
- Effects order on N leaching: CLITE ＞ Peat mosss ＞ Biochar ＞ PROFILE ＞ AXIS
- Effects order on K leaching: Peat mosss ＞ CLITE ＞ Biochar ＞ PROFILE ＞ AXIS

# III. Spongy Grassland

- Spongy grassland for water storage:
- Canopy retention =

  (Saturated moisture — wilting point)×canopy biomass
- Soil water retention =

  (Field capacity — natural drying water content）×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

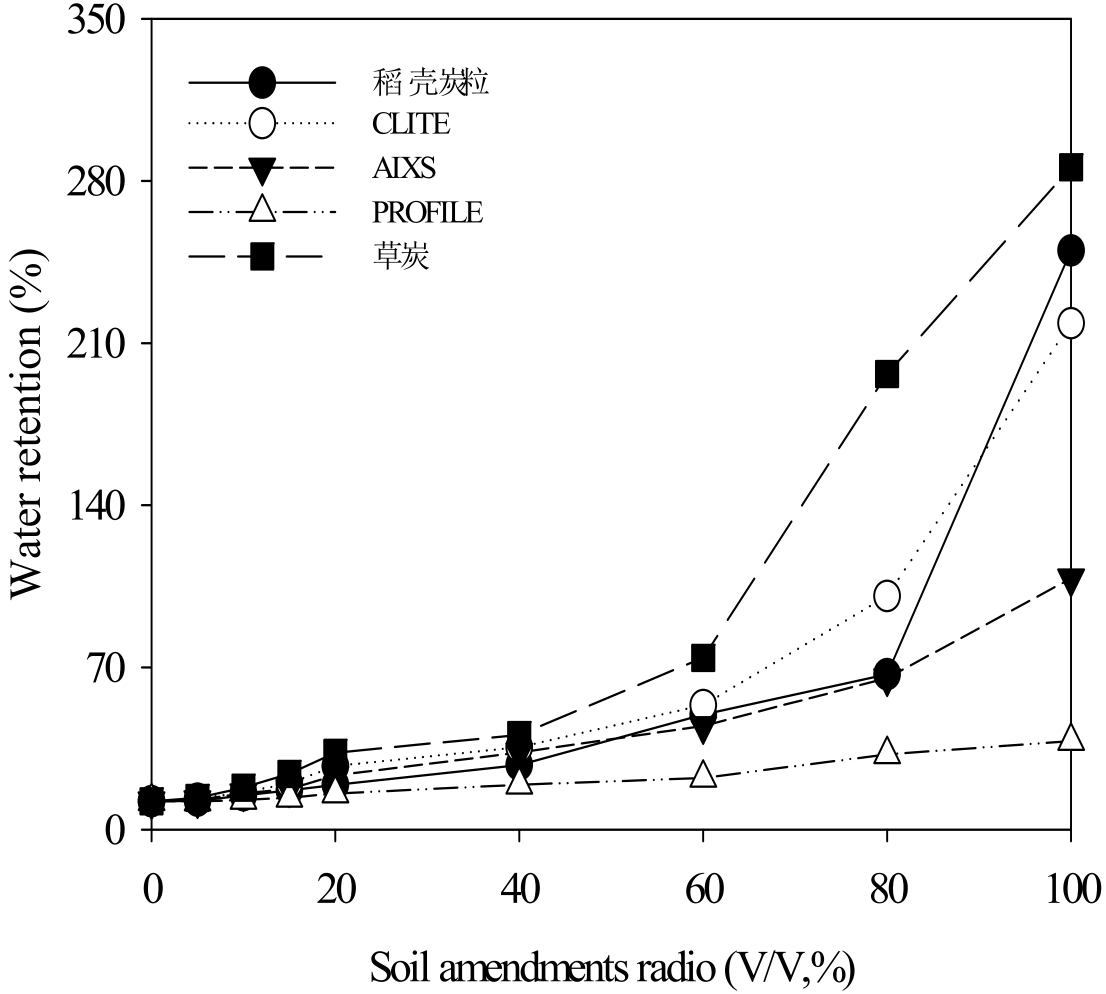
# Key 1

- Select flooding tolerance plants with lower ET

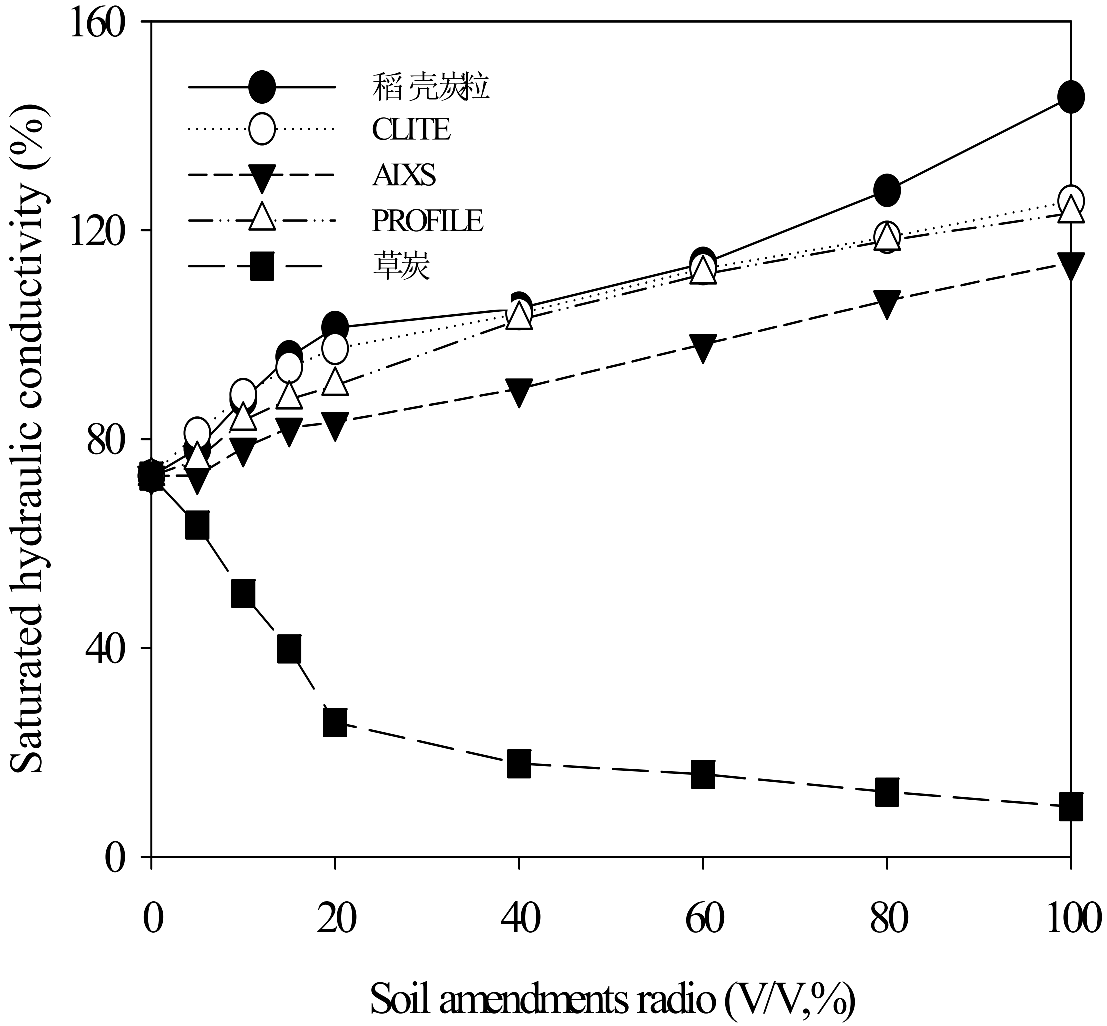
# Key 2

- Constructed the highly infiltration soil to reduce runoof.
- Infiltration rate >> precipitation.
- If not…

# Improvement of water retention



# Improvement of infiltration



# Key 3

- Water retention in grassland ≥ Plant water consumption

- Grassland water retention =

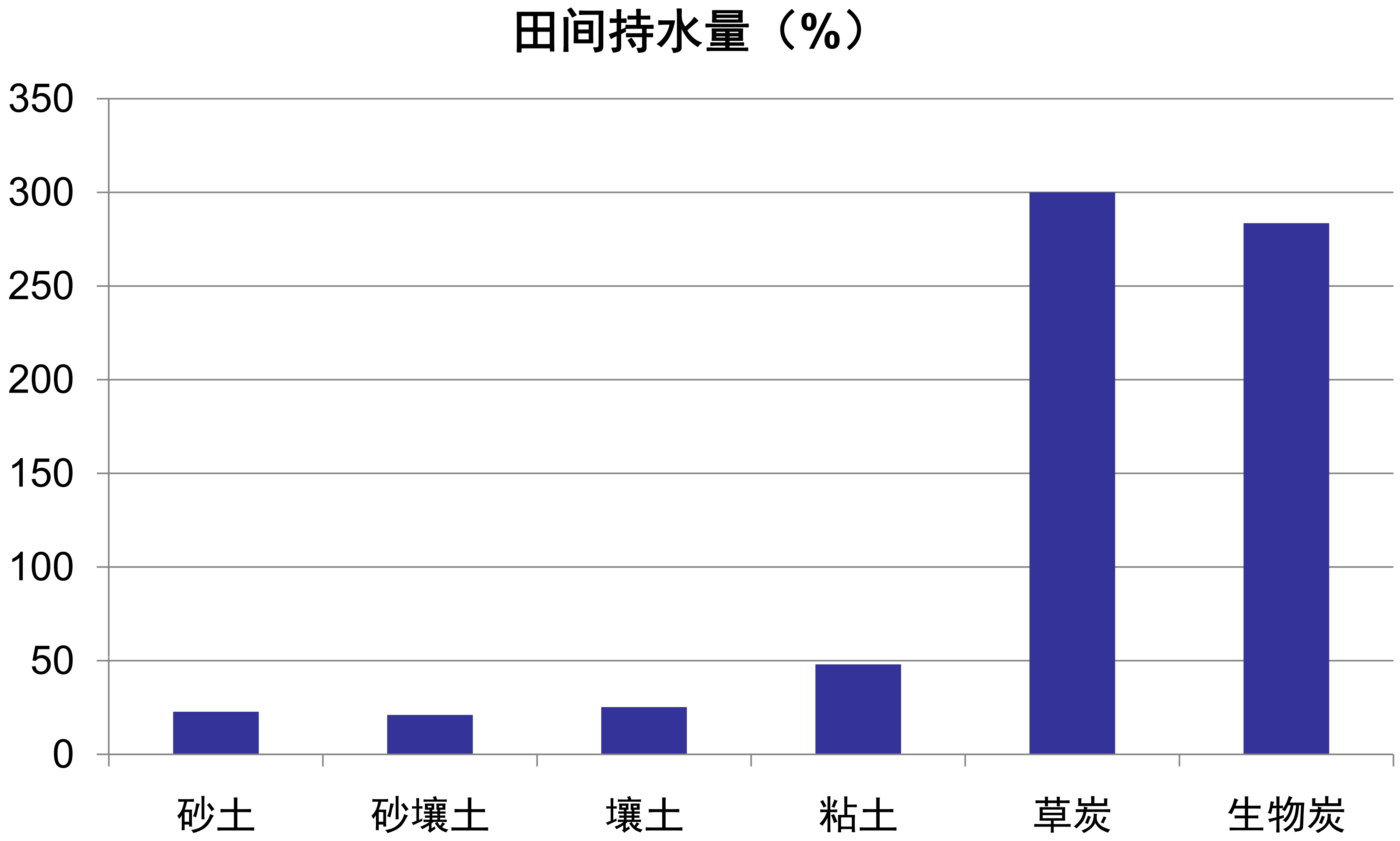
Plant tissue retention + soil retention + additional facility

- Plant water consumption = Evaportranspiration × days

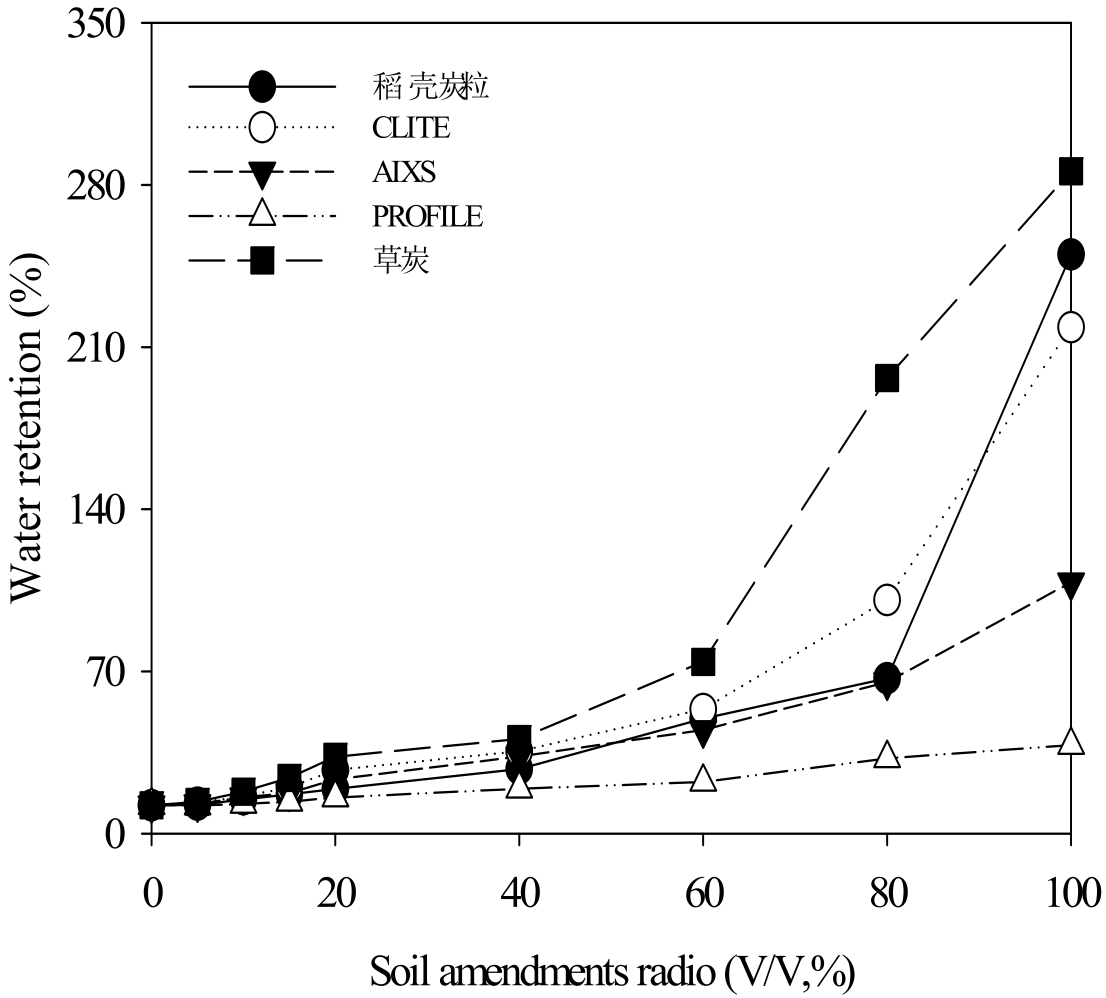
※ Plant species

※ Local weather

# Water retention of various soils

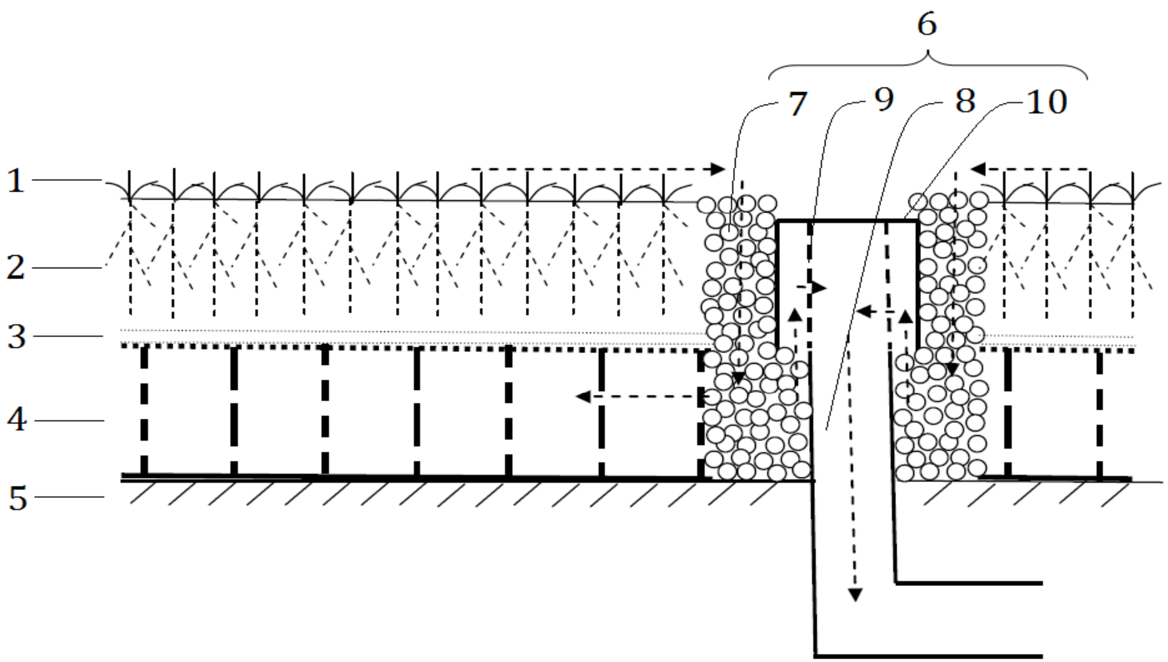


# Water retention improvement



# 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.



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# 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 ×30 mm/h = 60 mm/h＞ infiltration rate. ***Temporary waterlogged!***
- Water retention capacity of grassland = 300 mm ×30% = 90 mm.
- = 60 mm from road runoff + grassland 30 mm.
- ＞ 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: 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