NaCl

100 mmol L\(^{-1}\) NaCl

24 h

\[ p < 0.05 \]

K\(^+\) and Na\(^+\) contents in leaves

Net photosynthesis rate and transpiration rate of leaves were significantly reduced when roots and rhizomes individually and roots and rhizomes together were exposed to NaCl. The same treatments led to increases in osmolality and proline contents in leaves. There was a greater reduction in net photosynthesis rate and transpiration rate of leaves when roots and rhizomes were treated together with NaCl than treated separately. However, when roots and rhizomes were treated with NaCl separately, no significant differences in leaf water content, proline content, net photosynthesis rate and transpiration rate were observed, suggesting that the roots have a similar role to the rhizomes in response to salinity stress in *L. chinensis*. When roots and rhizomes were treated with NaCl either together or separately, the Na\(^+\) contents in roots, rhizomes and leaves were higher than those of controls by contrast, the K\(^+\) contents were lower than those of controls.

**Conclusions**

Rhizomes of *L. chinensis* are important in sensing and responding to salinity and have a similar function to that of roots in uptake and translocation of Na\(^+\) under salinity stress. Because rhizomes have smaller biomass and surface area than root systems, we speculate that rhizomes of *L. chinensis* may have greater capacity than roots for uptake and translocation of Na\(^+\) ions under salinity stress.

**Key words**

*L. chinensis*, Rhizomes, Roots, Na\(^+\) uptake, Salinity stress

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**PHYSIOLOGICAL ROLES OF RHIZOMES IN RESPONSE TO SHORT-TERM SALINITY IN *LEYMUS CHINENSIS***

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**Abstract**

Background and Aims: Rhizomes in clonal plants play a key role in storage and transport of nutrients as well as production of tillers. However, physiological functions of rhizomes in response to abiotic stress are poorly known. We investigated physiological responses of *L. chinensis* to salinity.

Methods: We measured the following physiological parameters after 24 h exposure of roots and rhizomes separately and exposure of roots and rhizomes together to 200 mmol L\(^{-1}\) NaCl: water and proline content in leaves, K\(^+\) and Na\(^+\) contents in leaves, roots and rhizomes, and osmolality, net photosynthesis rate and transpiration rate in leaves.

Key Results: Net photosynthesis rate and transpiration rate of leaves were significantly reduced when roots and rhizomes individually and roots and rhizomes together were exposed to NaCl. The same treatments led to increases in osmolality and proline contents in leaves. There was a greater reduction in net photosynthesis rate and transpiration rate of leaves when roots and rhizomes were treated together with NaCl than treated separately. However, when roots and rhizomes were treated with NaCl separately, no significant differences in leaf water content, proline content, net photosynthesis rate and transpiration rate were observed, suggesting that the roots have a similar role to the rhizomes in response to salinity stress in *L. chinensis*. When roots and rhizomes were treated with NaCl either together or separately, the Na\(^+\) contents in roots, rhizomes and leaves were higher than those of controls by contrast, the K\(^+\) contents were lower than those of controls.

Conclusions: Rhizomes of *L. chinensis* are important in sensing and responding to salinity and have a similar function to that of roots in uptake and translocation of Na\(^+\) under salinity stress. Because rhizomes have smaller biomass and surface area than root systems, we speculate that rhizomes of *L. chinensis* may have greater capacity than roots for uptake and translocation of Na\(^+\) ions under salinity stress.

Key words: *L. chinensis*, Rhizomes, Roots, Na\(^+\) uptake, Salinity stress
羊草（学名：Leymus chinensis）是一种多年生根状茎型禾草，是我国东北松嫩草原、华北、西北等地草原的优势草种之一，也是我国目前干草捆出口最多的牧草品种。其不仅营养价值高、适口性好，而且具有较强的抗寒、耐干旱、耐啃食和践踏等优良特性。作为一种典型的根状茎型克隆植物，羊草根茎不但在养分的储存与运输、分蘖茎的形成等方面，而且在克隆基株间的克隆整合、形态可塑性和分工合作等方面都起到十分重要的作用。

异质生境下克隆植物的表型可塑性和生理整合已经开展了深入的研究，两者都被普遍看作是异质生境下克隆植物的适应对策。根茎在植物无性繁殖、感知斑块的质量和克隆植株之间信息交流和物质交换中的作用已有报道。但以往的研究往往把根茎简单的当作同化物的存储库和分蘖茎的生产者来对待，而对根茎在养分吸收、转运及其在响应和适应环境胁迫中的作用却研究很少。因为根与根茎生长在同样的土壤环境中，因此，根茎类植物在遭受外界环境胁迫时根茎可能与根一样参与植物对环境胁迫的响应和适应。

近年来我国内陆草原由于管理不当和过度利用，沙化和盐碱化日益严重，牧草产量、质量大幅度下降，草原逐步退化，土壤盐碱化问题已为国内外科研工作者所重视。此外，我国由于不良的耕作和灌溉方式以及使用劣质水灌溉，每年还产生大量的次生盐渍化土壤。盐分对植物的生长发育具有显著的影响，整体上表现为盐胁迫抑制植物组织和器官的生长，加速发育进程，缩短营养生长期和开花期等（沈义国和陈受宜）。虽然对羊草盐碱胁迫的生理学研究已有报道，但在这些研究中羊草的根和根茎同时给予盐（碱）胁迫处理，因此这些结果并不能揭示根和根茎各自在胁迫生理过程中的作用。本文以人工栽培的羊草幼苗为试验材料，研究了在短期胁迫条件下根茎在羊草应答盐胁迫过程中的生理功能，与根系在该过程中的作用进行了比较。

材料和方法

试验于2003年6月在中国科学院植物研究所温室进行。羊草种子于2004年秋在中国科学院植物研究所多伦恢复生态学试验示范研究地内采集。羊草幼苗在中国科学院植物研究所温室中培养。温室最高日温25～28℃，最低夜温12～15℃，最高光合有效辐射1000～1500 μmol m⁻² s⁻¹。为提高种子萌发率将种子于冰箱中冷藏2周，再用清水浸泡2～4 h后播种。挑选籽粒饱满的种子，播种到塑料花盆中（直径：12 cm，高度：15 cm）。培养基质选用草碳、蛭石和珍珠岩的混合体，体积比例为2:1:3。出苗后每隔2 d浇以200 μmol m⁻² s⁻¹浓度的KNO₃溶液。出苗后1周后选取有根茎且地上部和地下部长势一致的幼苗移到分根箱中（塑料花盆简单改装而成，中间用有机玻璃隔开，大小、培养基质同上），每分根箱移苗10株。缓苗2周后进行处理。实验设5个重复，A～E个处理，分别为：对照、胁迫根、胁迫根茎、同时胁迫根和根茎。用NaCl分别进行胁迫，进行处理时，胁迫部位加入200 mmol L⁻¹ NaCl溶液，非胁迫部位加入等体积的去离子水（图1）。处理后测定以下各项生理指标。羊草在分根箱中根和根茎的分布示意图。

图1 Schematic diagram showing the distributions of root and rhizome of Leymus chinensis in the growth chamber

Leymus chinensis

Fig. 1 植物对短期胁迫的响应

<table>
<thead>
<tr>
<th>材料和方法</th>
<th>实验</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
</tr>
</thead>
</table>

Na⁺K⁺HClO₃-HNO₃ 360 ℃ 5 h

24 h NaCl

1 200 μmol m⁻² s⁻¹

LI-6400

Pn 10 min

3 500 g/5 min

Na⁺K⁺HClO₃-HNO₃

30～35 ℃ 23～28 ℃

800～1 200 μmol m⁻² s⁻¹

2：1

D(C)E G

B(C)E G

A(C)E G

I(C)E G

200 mmol L⁻¹ NaCl

200 mmol L⁻¹ NaCl

30 ml

1/2 Hoagland

3：1

5

1/2

B(C)E G

A(C)E G

I(C)E G

200 mmol L⁻¹ NaCl

200 mmol L⁻¹ NaCl

30 ml

1/2 Hoagland

3：1

5

1/2

B(C)E G

A(C)E G

I(C)E G

200 mmol L⁻¹ NaCl

200 mmol L⁻¹ NaCl

30 ml

1/2 Hoagland

3：1

5

1/2

B(C)E G

A(C)E G

I(C)E G

200 mmol L⁻¹ NaCl

200 mmol L⁻¹ NaCl

30 ml

1/2 Hoagland

3：1

5

1/2

B(C)E G

A(C)E G

I(C)E G

200 mmol L⁻¹ NaCl

200 mmol L⁻¹ NaCl

30 ml

1/2 Hoagland

3：1

5

1/2

B(C)E G

A(C)E G

I(C)E G

200 mmol L⁻¹ NaCl

200 mmol L⁻¹ NaCl

30 ml

1/2 Hoagland

3：1

5

1/2

B(C)E G

A(C)E G

I(C)E G

200 mmol L⁻¹ NaCl

200 mmol L⁻¹ NaCl

30 ml

1/2 Hoagland

3：1

5

1/2
结果与分析
叶片含水量和地上生物量
单独胁迫根茎与单独胁迫根对叶片含水量没有显著影响,但同时胁迫根和根茎可以显著降低叶片含水量（表1）。用%&'（）胁迫羊草后,羊草地上部的鲜重和干重没有显著变化（表2）,并且胁迫根、胁迫根茎与同时胁迫根和根茎没有差异。这可能与处理时间太短有关。

表1 NaCl对羊草叶片脯氨酸含量的影响

<table>
<thead>
<tr>
<th>处理</th>
<th>FW</th>
<th>DW</th>
<th>叶片渗透势（kPa）</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.29 ± 0.09*</td>
<td>0.08 ± 0.02*</td>
<td>72 ± 0.03*</td>
</tr>
<tr>
<td>Treating rhizome</td>
<td>0.28 ± 0.14*</td>
<td>0.09 ± 0.02*</td>
<td>69 ± 0.05*</td>
</tr>
<tr>
<td>Treating root</td>
<td>0.29 ± 0.05*</td>
<td>0.10 ± 0.01*</td>
<td>67 ± 0.04*</td>
</tr>
<tr>
<td>Treating root and rhizome</td>
<td>0.22 ± 0.03*</td>
<td>0.10 ± 0.03*</td>
<td>54 ± 0.03*</td>
</tr>
</tbody>
</table>

脯氨酸含量的影响
植物体内脯氨酸浓度的变化是植物对盐和干旱胁迫反应敏感的重要生理指标之一。植物体内游离脯氨酸含量的变化在一定程度上可以反应植物对环境胁迫的适应能力。从图可以看出,与对照相比,胁迫羊草不同部位都引起了羊草叶片脯氨酸含量的增加,但胁迫根、胁迫根茎、同时胁迫根和根茎之间没有显著性差异,说明羊草的根、根茎都能感受盐胁迫,并对盐胁迫反应的敏感程度相似。

图显示了不同处理对羊草叶片渗透势的影响。从图可以看出,胁迫显著增加叶片的渗透势。胁迫根、胁迫根茎与同时胁迫根与根茎的叶片的渗透势分别比对照增加8%、8%、8%，而胁迫根与胁迫根茎两处理间叶片的渗透势没有显著性差异。同时处理根和根茎时,羊草叶片渗透势高于根和根茎分别受胁迫,表明根和根茎在诱导羊草叶片有效渗透溶质的增加具有累加效应。

2.2 Fougère et al. 1991

2.3 NaCl

2.4 NaCl

Fig. 2 Changes in leaf proline content in response to treatments of root, rhizomes and roots and rhizomes together of Leymus chinensis. n = 3; p < 0.05. Vertical bars represent mean ± SD. The different letters represent significant differently among treatments (p < 0.05).
单独胁迫根和单独胁迫根茎时羊草叶片净光合速率下降幅度分别为$!#$%和$!&#'\%$,两处理间没有显著差异,但都显著低于同时胁迫根和根茎处理。蒸腾速率也表现出相似的规律,即单独胁迫羊草根或根茎叶片蒸腾速率的降低幅度显著低于同时胁迫根和根茎。

图显示胁迫根、胁迫根茎、同时胁迫根和根茎叶片中$I\text{C}$含量均高于对照,这一规律与以往的试验结果基本一致。通过图还可以看出,胁迫根茎时叶片中$I\text{C}$含量为$(&($(!86，显著高于对照和胁迫根处理时叶片中的$I\text{C}$含量$'&F$!(86，说明根茎具有吸收$I\text{C}$功能,且吸收$I\text{C}$的能力强于根吸收$I\text{C}$的能力。在测定叶片中$I\text{C}$含量的同时也测定了根和根茎中的$I\text{C}$的含量,如图和图,从图可以看出,不同处理下根中的$I\text{C}$含量分别为:$!&"$、$'H#A$和$($#H$，分别比对照高$A'#\%$、$'H#A\%$和$($#H\%$，胁迫根显著高于胁迫根茎处理,而与同时胁迫根和根茎处理没有差异。根茎中的$I\text{C}$含量在各处理间有所不同,同时处理根和根茎时,根茎中的$I\text{C}$含量最高,胁迫根茎的其次,单独胁迫根时根茎中的$I\text{C}$含量最低。
单独胁迫羊草根、根茎和同时胁迫羊草根和根茎对羊草根、根茎和叶片中"#&、'&和'&含量的影响。

叶片的渗透势升高，水势下降，水势的微小改变就会导致气孔导度和蒸腾作用的显著变化。植物在盐胁迫条件下，叶绿素含量下降，光能利用和光同化能力降低，导致光合速率下降。升高，叶片的蒸腾速率降低。叶片的渗透势升高，水势下降，水势的微小改变就会导致气孔导度和蒸腾作用的显著变化。

胁迫根和根茎所导致的光合和蒸腾速率的下降可能由于在盐胁迫条件下羊草合成植物激素，合成的诱导气孔关闭，从而降低光合和蒸腾速率。盐胁迫诱导的合成和参与诱导气孔关闭已有报道。分别胁迫根和根茎的两个处理比较来看，胁迫根和与胁迫根茎后，叶片含水量、脯氨酸含量、叶片净光合速率和蒸腾速率没有差异，表明根茎与根对盐胁迫反应的敏感程度相似。

单独胁迫根茎或者同时胁迫根系和根茎都可以显著增加叶片、根茎和根系内的"#&含量，表明羊草根茎与根系一样参与"#&的吸收和转运。以往的研究认为羊草根茎的主要功能是产生分蘖茎和储存同化物以利于羊草越冬。鉴于羊草根茎的生物量和表面积都远远低于根系，因此可以推断羊草在盐胁迫条件下根茎吸收"#&离子的能力甚至高于根系。羊草根系与根茎在"#$%胁迫条件下所导致的羊草"#&累积的差异也可能在于：质膜上逆向转运体的活性；根茎

Tissues exposed to NaCl

Fig. 5 Effects of treatments of roots rhizomes and roots and rhizomes together with NaCl on K，K'，Na，Na'，K'，K+，NaCl and Na+ contents in leaves，roots and rhizomes of Leymus chinensis

Note see Fig. 2


