Sugar transport and nitrate reductase activity rate in roots affect plant adaptation to cold and warm climate

From the endless sea………
And a drop of mine

U. Kafkafi
Agrostis scabra (Hot climate acclimated) exhibited a less severe decrease in root viability than the Agrostis sp. L-93 (cold climate acclimated).

Why?


By Bingru Huang and Yan Xu
Plant tolerance to high soil temperature is related to efficient expenditure and adjustment of C- and N- allocation patterns between growth and respiration.

Shimon Rachmilevitch, Bingru Huang and Hans Lambers
Assimilation and allocation of carbon and nitrogen of thermal and nonthermal Agrostis species in response to high soil temperature

Why?
Nitrate is reduced to ammonia by a two-step process catalyzed by the enzymes nitrate reductase (NR) and nitrite reductase (NiR).

\[
\text{Step 1: } \ \ \ \ \ \ \ \ \ \ \ \ NO_3^- + 2H^+ + 2e^- \rightarrow NO_2^- + H_2O \\
\text{Step 2: } \ \ \ \ \ \ \ \ \ \ \ \ NO_2^- + 8H^+ + 6e^- \rightarrow NH_4^+ + H_2O
\]

How much sugar is consumed in ATP production?

2 ATPs and 8 electrons per molecule of NH\(_4^+\)!!!!!
NH$_3$ assimilation (Marschner)
The major stations in this road trip are specified, How much Sugar is consumed in this trip?
Can it be supplied fast enough from the leaves to the last finest root cell?

Model of ammonia assimilation pathways. (1, 2) Glutamine synthetase-glutamate synthase pathway, with low NH$_3$ supply (1) and with high NH$_3$ supply (2). (3) Glutamate dehydrogenase pathway. GOGAT: Glutamine-oxoglutarate aminotransferase
Sugar supplies the Energy
Pea (legume)
45% of Nitrate uptake
Was reduced in the root

Source: van Beusichem
Personal communication
Maize - 35 % of Nitrate uptake was reduced in the root

Source: van Beusichem
Personal communication
sunflower – (a Summer crop)

17% of Nitrate uptake was reduced in the Root

Source: van Beusichem
Personal communication
General findings:

*temperate species* carry out most of their nitrate assimilation *In the root*

While *tropical species* assimilate most of their nitrate *In the leaves*

These conclusions are primarily based on measurements of the distribution of nitrate reductase activity (NRA) between root and shoot and the relative concentrations of nitrate and reduced N in the xylem sap (Pate, 1980; Sprent, 1980).
The energy requirements of \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) absorption and assimilation constitute a significant portion of root respiration.

Arnold J. Bloom, Scott S. Sukrapanna, and Robert L. Warner
Root Respiration Associated with Ammonium and Nitrate Absorption and Assimilation by Barley
Strawberry root temperature

Ganmore & Kafkafi 1983

on 7 mM NO$_3^-$

10 ºC 17 ºC 25 ºC 32 ºC

NH$_4^+$ 0 NO$_3^-$ 7mM

Sugar (%) 3.4 2.18 2.15 1.1

on 7 mM NH$_4^+$

10 ºC 17 ºC 25 ºC 32 ºC

NH$_4^+$ 7mM NO$_3^-$ 0

Sugar (%) 2.4 1.6 1.1 0
Why one plant is more sensitive to high temperature than the other?

Observations:
1. Increasing strawberry root temperature resulted in increasing amounts of dying roots.
2. Part of the roots remain healthy.
3. The higher the root temperature the lower is the sugar content of the root mass.

With Nitrate, the dying root process with temperature increase is slower than with ammonium.
Effects of Local Nitrogen Supply on Water Uptake of Bean Plants in a Split Root System

Guo S., Shen Q. and Brueck H. 2007
Journal of Integrative Plant Biology
49(4): 472-480

The same sugar supply source:
Ammonium consume more in the root

In the same plant:
Nitrate roots – healthy
Ammonium roots - brown

Both at the same root temperature
Adaptation in Tomato

At high root temperature:
most of the nitrate is in the Top
minimum is found in the root

Root survival

depends on the rate of sugar supply and consumption

**Ammonium** fed roots consume more sugar since **All** the ammonium is metabolized in the root

**Nitrate** fed roots split the sugar consumption between roots and shoots
Increasing root temperature increases the root sugar consumption for respiration.

The cell dies due to ammonia toxicity since no sugar is left for the completion of the GS-GOGAT cycle for amino compounds production in the root.
NO₃⁻ absorption requires:
1 to 2 ATP
Or
0.16 to 0.32 mol CO₂
Per mol NO₃⁻ absorbed

The reduction of NO₃⁻ to NH₄⁺ requires:
8 to 12 mol ATP
Or
1.3 to 1.9 mol CO₂
per mol NO₃⁻ assimilated

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Absorption and Assimilation by Barley
Mol CO$_2$ evolved per mol NO$_3^-$ absorbed and assimilated

<table>
<thead>
<tr>
<th>Plant</th>
<th>CO$_2$ evolved</th>
<th>NO$_3^-$ absorbed and assimilated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perennial ryegrass</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>Wild radish</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>Carex diandra</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>Cowpea</td>
<td>0.47</td>
<td>2.6 mol CO$_2$ evolved per mol NO$_3^-$ assimilated</td>
</tr>
</tbody>
</table>

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Root Respiration Associated with Ammonium and Nitrate
Absorption and Assimilation by Barley
Suggestion:

Plant survival at high root temperatures depends on the ability to minimize sugar consumption for nitrate reduction in the root, sparing the sugar needed for root cells respiration.
Kafkafi’s team (1955 - today)

Thank you