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Root-soil-contact influences on maize root growth, nutrient uptake, and nitrogen-cycling microorganisms in the rhizosphere

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Introduction:

- The rhizosphere is a rich niche of microorganisms, including plant growth promoters and drivers of biogeochemical cycles.
- Root-soil interactions cover a wide range of biological and physicochemical processes with direct effects on plant growth.
- Root hairs are an important root trait that ensures root-soil contact.
- **Approaching the rhizosphere in response to root-soil contact is an important strategy to;**
  - ✓ **improve crop growth productivity**
  - ✓ **fulfill global food demand.**

This study explored the heterogeneity of the maize root system in response to reduced root-soil contact.

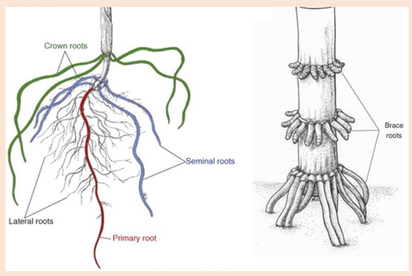


Fig. 1: The root system of typical wildtype of *Zea mays*; *Adapted from Hochholdinger, 2009.*

Results:

- Roots of *Zea mays* wildtype and *rth3* mutant preferentially tend to grow into the artificial pores with different behaviors depending on genotype and root type.

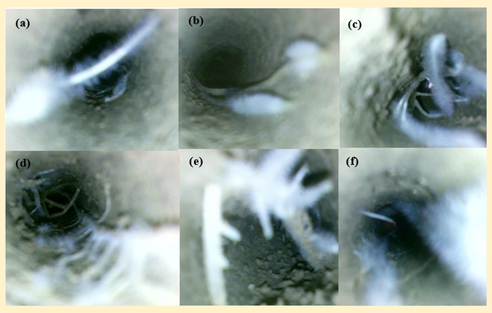


Fig. 4: The endoscopic images of the root growth behavior of *Zea mays* wildtype inside the artificial soil pores (a-f).

Fig. 5: Photographic images of growth characteristics of the crown and seminal roots of *Zea mays* wildtype (a & c) and *rth3* mutant (b & d) inside the artificial soil pores.

- Growth of young maize plants was not significantly affected by artificial pores but by the presence or absence of root hairs.

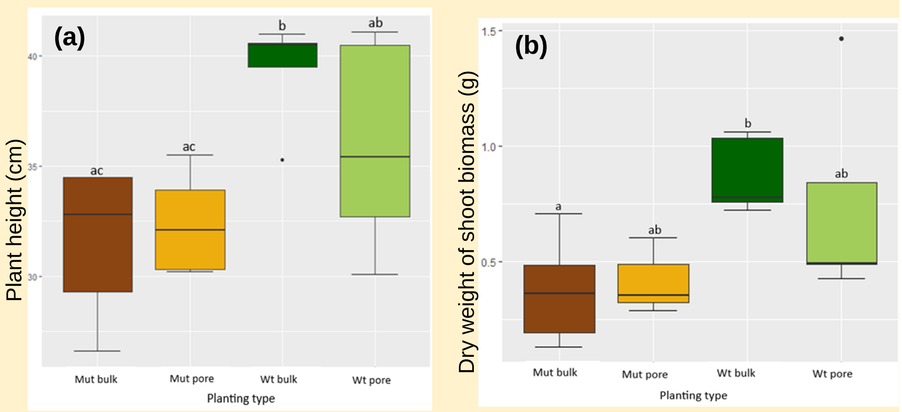
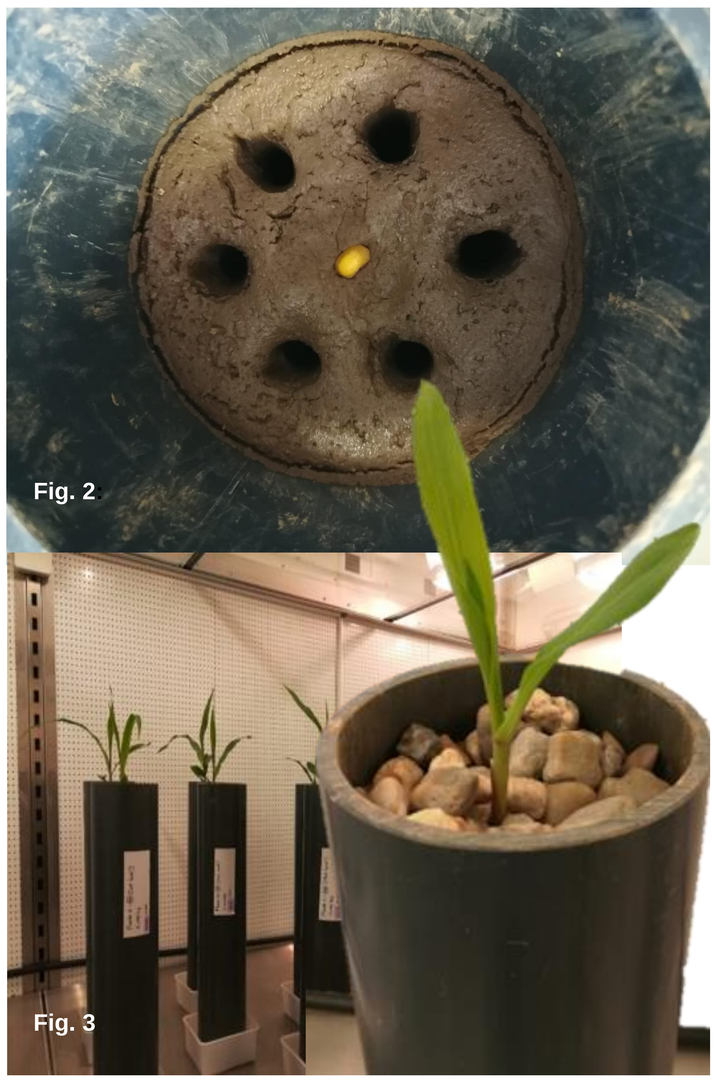


Fig. 6: Height (a) and Dry weight of shoot biomass (b) of *Zea mays* wildtype (Wt) and *rth3* mutant (Mut) at the harvesting point grown in soil with (pore) and without (bulk) the artificial pores.

- Nutrient uptake (except the S) of young maize plants was not significantly affected by artificial pores.

Nutrient	With pores		Without pores	
	Wt	*rth3*	Wt	*rth3*
N (g/kg)	50 ± 1^{a}	49 ± 2^{a}	47.2 ± 0.4^{a}	50 ± 1^{a}
C (g/kg)	413 ± 5^{a}	415 ± 2^{a}	323 ± 91^{a}	415 ± 3^{a}
P (mg/L)	17 ± 5^{a}	15 ± 2^{a}	18 ± 3^{a}	13 ± 3^{a}
K (mg/L)	172 ± 32^{a}	204 ± 22^{a}	221 ± 42^{a}	190 ± 39^{a}
Ca (mg/L)	80 ± 25^{a}	60 ± 5^{a}	79 ± 14^{a}	47 ± 11^{a}
Mg (mg/L)	12 ± 3^{a}	11 ± 1^{a}	13 ± 2^{a}	8 ± 2^{a}
S (g/kg)	4.12 ± 0.17^{a}	3.28 ± 0.03^{c}	3.24 ± 0.12^{b}	3.58 ± 0.07^{b}
Al (mg/L)	0.12 ± 0.05^{a}	0.24 ± 0.14^{a}	0.16 ± 0.08^{a}	0.23 ± 0.08^{a}
Fe (mg/L)	1.23 ± 0.28^{a}	3.18 ± 1.03^{a}	1.23 ± 0.17^{a}	2.19 ± 0.43^{a}
Zn (mg/L)	0.20 ± 0.05^{a}	0.18 ± 0.02^{a}	0.20 ± 0.03^{a}	0.17 ± 0.04^{a}

Table 1*:* Shoot nutrient content of *Zea mays* wildtype (Wt) and *rth3* mutant (*rth3*) plants grown in soil with and without artificial pores.



Highlights:

- *Zea mays* wildtype plants show significantly higher shoot and root growth than the *rth3* mutant.
- The root hairs play an important role in improving root-soil contact.
- Root growth behaviors inside the pores largely vary depending on the genotype and the root type.
- Plants compensate for reduced root-soil contact by reducing biomass while maintaining nutrient levels in the biomass.
- Root-soil contact largely influences the abundance of bacteria including nitrifiers and denitrifiers.
- *Zea mays* wildtype plants harbor a higher abundance of bacteria than the root hairless *rth3* mutant.
- The abundance of archaea is less responsive to root-soil contact and they prefer the pore walls over the bulk soil.
- (The artificial) pore walls harbor a higher abundance of denitrifiers than the bulk soil, suggesting an anaerobic and nitrate-rich environment on the pore walls.
- Soil pores can play ambiguous roles with either favorable or unfavorable impacts on plant growth.

Methods:

- The *Zea mays root hairless 3* (*rth3*) mutant was comparatively studied with its corresponding wild-type for 21 days in a climate chamber(Fig.3).
- Root-soil contact was reduced by artificial soil pores (Fig.2) or the absence of root hairs (*rth3* mutant).
- Determined the influences on:
  - ✓ Root growth and pore utilization (endoscopic analysis)
  - ✓ Shoot nutrient uptake (CHNS analysis and nitric acid digestion followed by flame AAS and ICP-OES analysis)
  - ✓ Microbial abundance (qPCR analysis)
    - **Bacteria (*16S rRNA*)**
    - **Archaea (*16S rRNA*)**
    - **Nitrifying bacteria (*amoA*)**
    - **Denitrifiers (*nirK*)**

Results:

- Under complete root-soil contact, wildtype plants hosted a significantly higher abundance of bacteria than the *rth3* mutant.
- Both genotypes showed a significant and gradual decrement in bacterial abundance with the reduction of root-soil contact.
- The artificial pore walls harbored a higher abundance of archaea over the bulk soil.

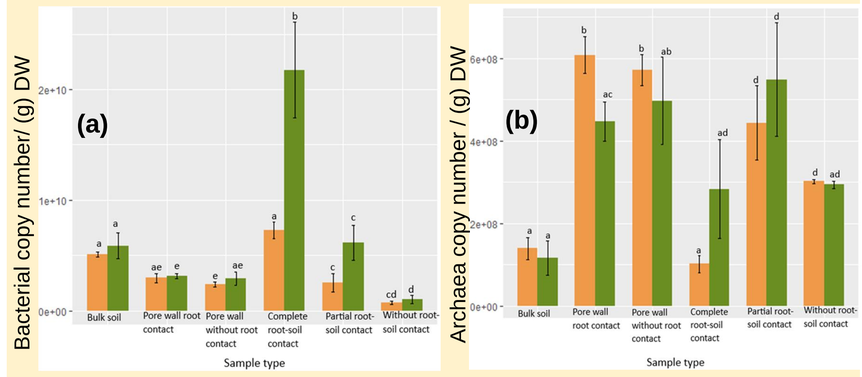


Fig. 7: Abundance of the 16S rRNA gene of bacteria (a) and archaea (b) under different root-soil contact conditions.

- Both genotypes showed the highest abundance of nitrifying bacteria in the rhizosphere with complete root-soil contact**.**
- The abundance of both nitrifiers and denitrifiers in both genotypes gradually declined with the reduction of root-soil contact.

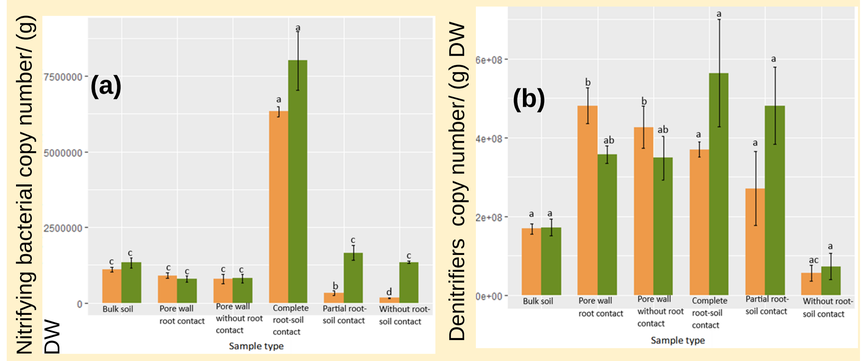


Fig. 8: Abundance of nitrifying (*amoA*) bacteria (a) and denitrifiers (*nirk*) (b) under different root-soil contact conditions.

Root-soil contact is important for proper plant performance and rhizosphere functions and the plant can (only) compensate to some extent reduced contact.

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PHENOROB

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