Rhizobacteria Mediated Changes in Soil Physical and Hydrological Properties

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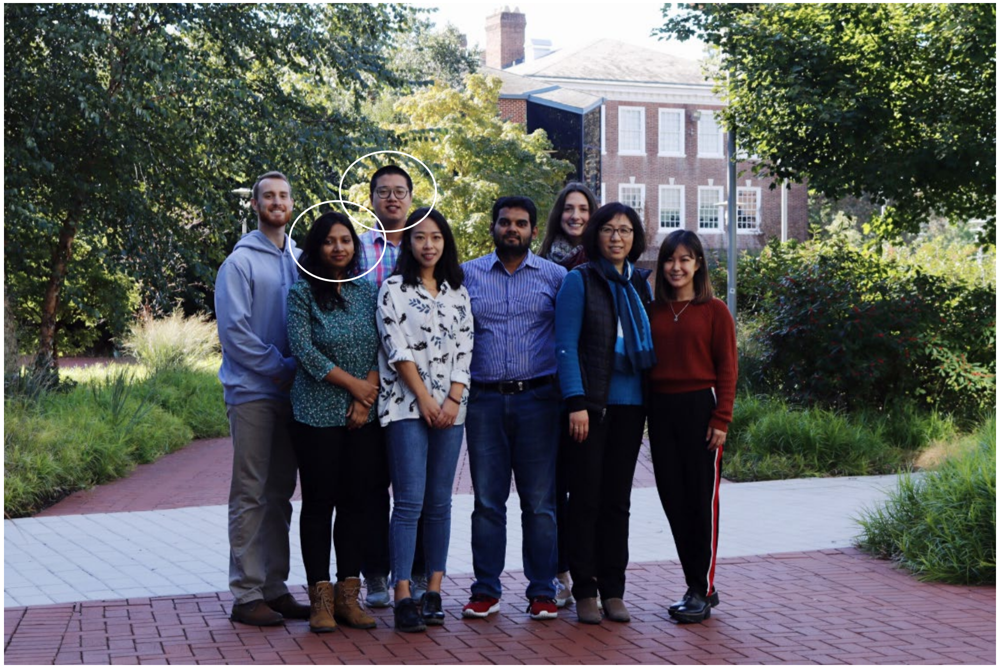


(Saiqi Zeng, Fatema Kaniz)

(Dr. Harsh Bais, UD)

USDA

National Institute of Standards and Technology

NIST National Institute of Standards and Technology U.S. Department of Commerce

CSREES USDA EDUCATION RESEARCH EXTENSION

Food security and water resources

(Sposito, VZJ, 2013)

- The projected global human population: ***> 9 billion in 2050 (30% increase from the current population)***

- The large increase in food production will have to mainly come from increasing crop yield (i.e., ***crop intensification***)
  - Land conversion for crop cultivation is nearing its ***planetary limit***
  - **Blue water** use by croplands is also nearing its ***planetary limit***

- "An evident opportunity to meet the global food demand is by optimizing green water use on existing croplands without further over-taxing either the land or the blue water resources of the world" *(Rockström et al., 2009).*

- **Green water:** Water in soil that remains potentially available to plant roots and soil biota after precipitation losses to runoff and deep percolation have occurred *(Rockström et al., 2009).*

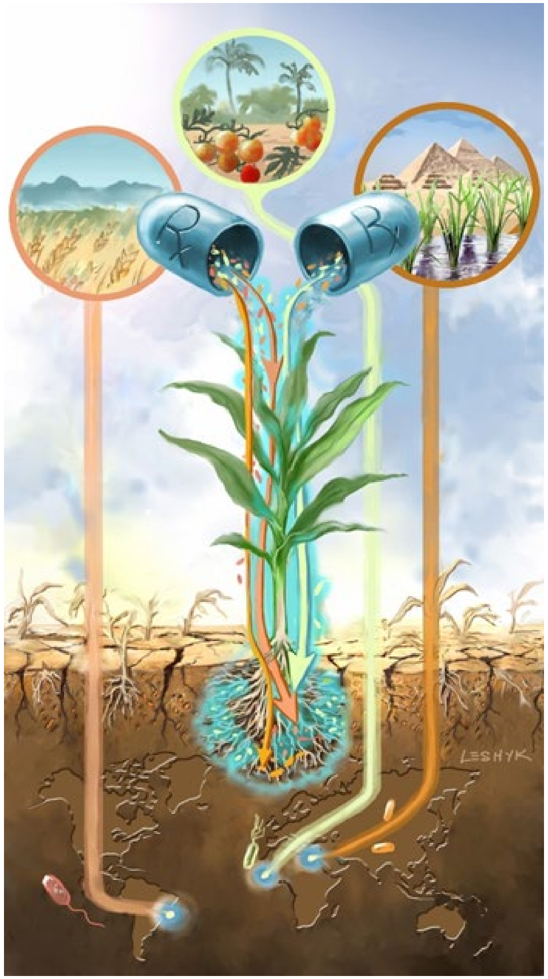
The Challenge to vadose research

- "The challenge to vadose zone research is to increase both ***green water availability*** and ***productive green water flow*** in croplands" *(Sposito, VZJ, 2013).*

- A potential strategy is to promote the efficacy of the **rhizosphere processes** in ways to increase transpiration and reduce evaporation.

- ***Rhizosphere engineering*** – develop innovative approaches to **modify** soil properties that favor the above desired outcome.

- Plant growth promoting rhizobacteria (PGPR) may play an important role in promoting beneficial feedback between soil and plant.



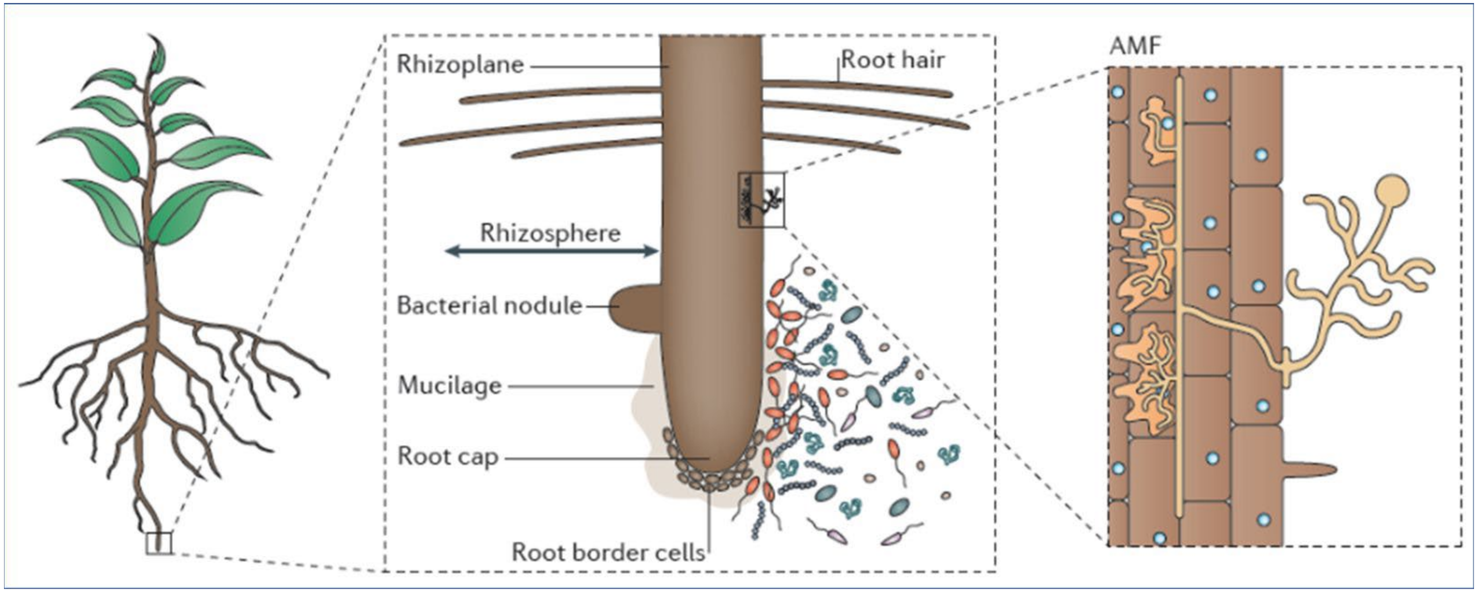
The rhizosphere

The rhizosphere is the zone of soil surrounding a plant root where the biology and chemistry of the soil are influenced by the root.

and physics

and physical + hydrological

- A few mm wide
- An area of intense biological and chemical activity influenced by compounds exuded by the root (***mucilage***), and by microorganisms (***EPS***)



(Phillipott et al, 2013)

Objectives

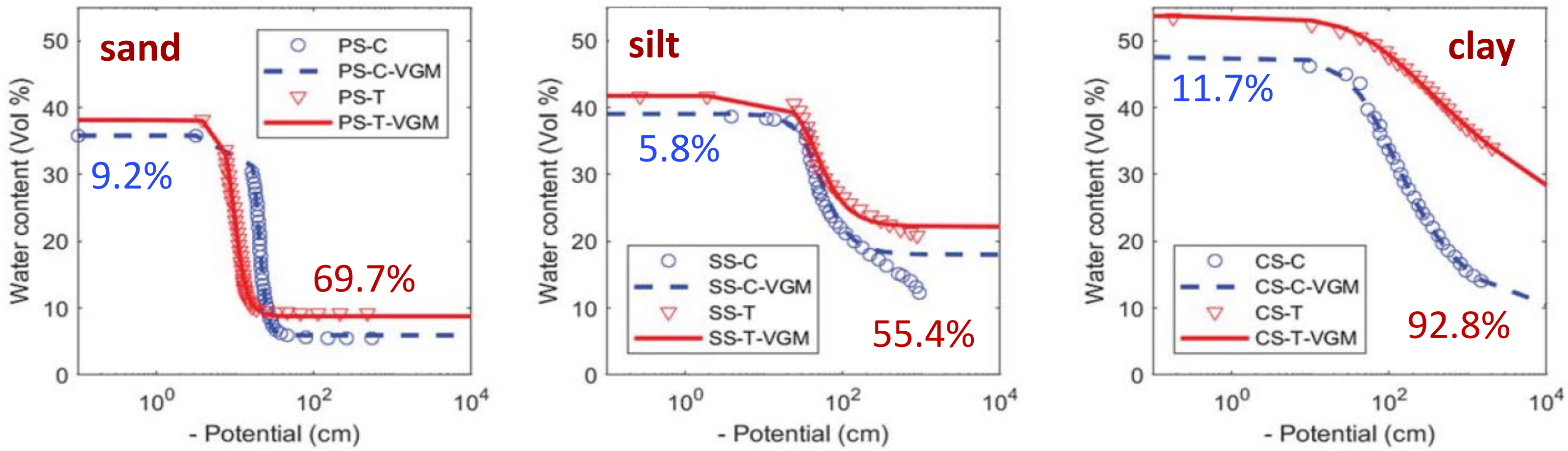
- To measure/demonstrate/quantify how soil microbes influence soil physical and hydrological properties (water retention, evaporation, hydraulic conductivity, infiltration)
- To identify the mechanisms responsible for the microbial-mediated changes in soil biophysical properties and processes

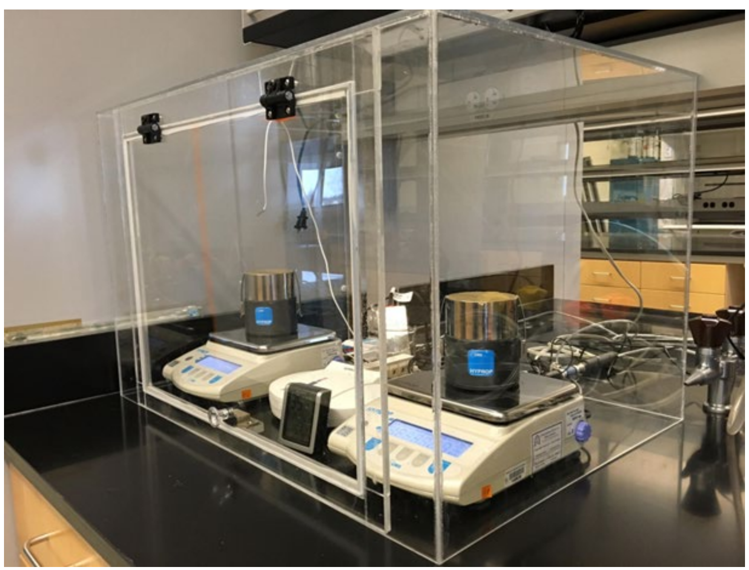
A plant growth-promoting rhizobacterium *Bacillus subtilis* (**UD1022**) and its mutant, with EPS producing genes inhibited (**eps-**) were used in this study

(https://www.udel.edu/udaily/2018/january/basf-biofungicide-patents-janine-sherrier-harsh-bais/)

Water characteristic curves

(Zheng et al., 2018)



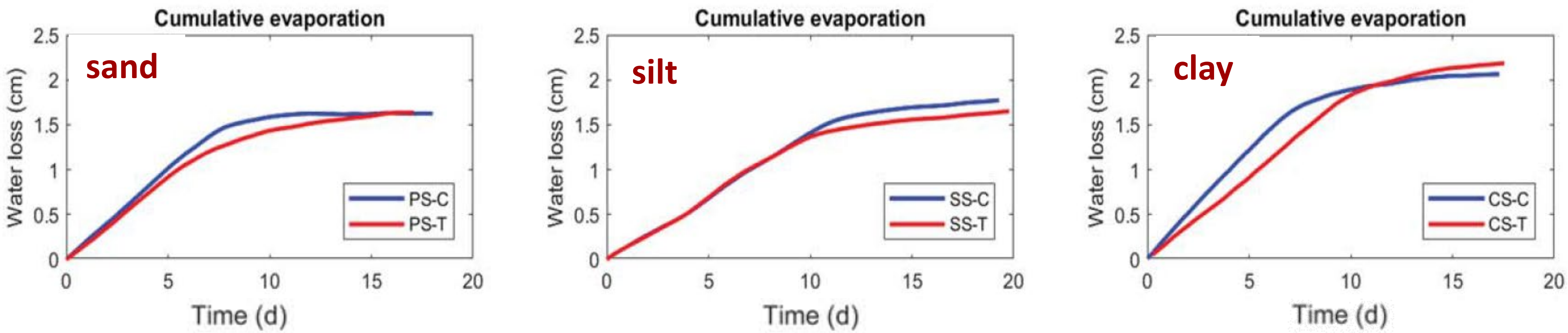


HYPROP *(Decagon Devices)*

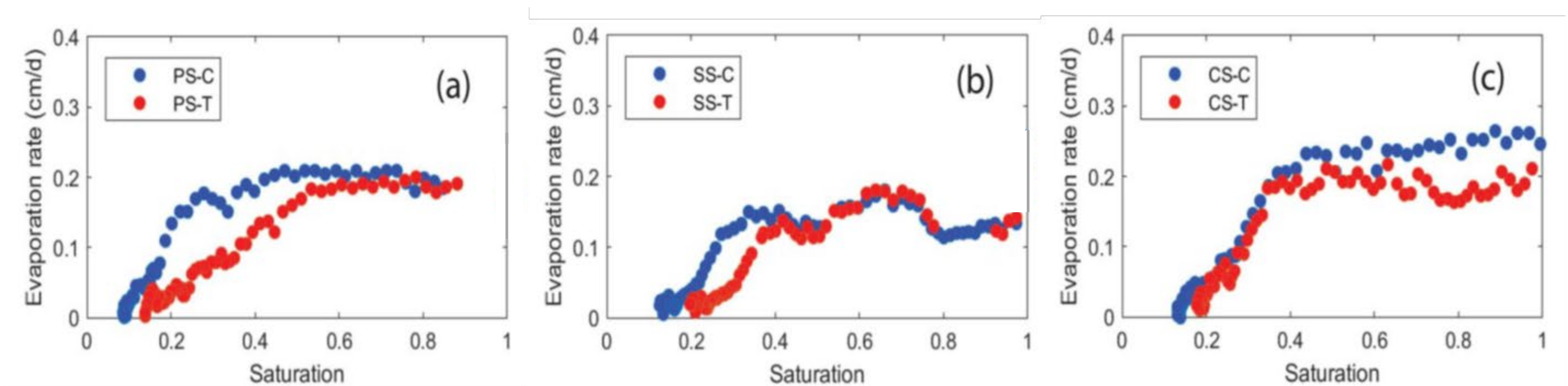
- At a given water potential, treated samples retained more water;
- The effect was more significant at low water content;
- The effectiveness of UD1022 in increasing water retention was different for different textured soils.

Evaporation and water loss

(Zheng et al., 2018)

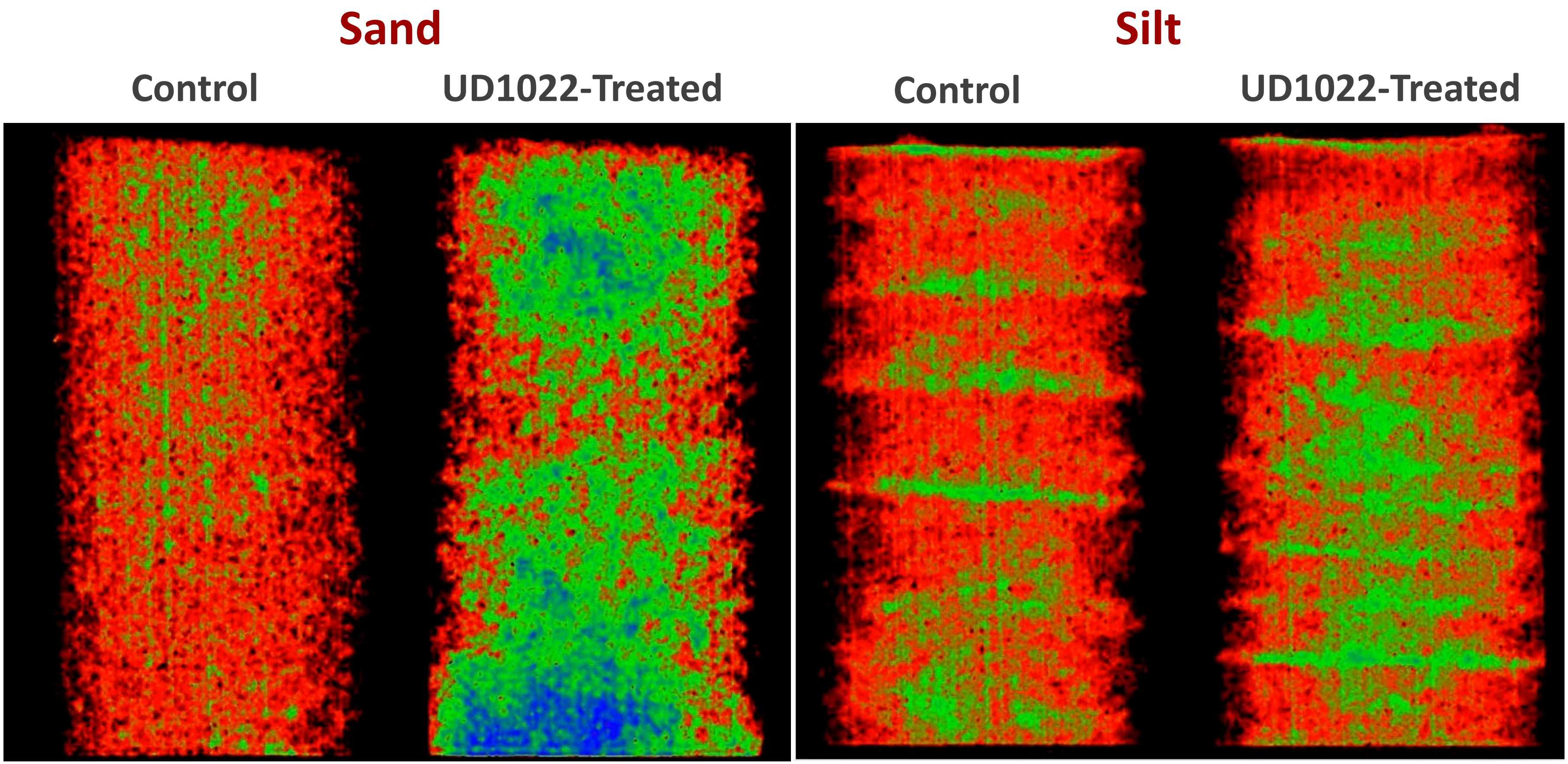


- Treated samples: less cumulative evaporation during all or part of duration



- Treated samples: slower evaporation rate at all soil moisture level (sand) or at low water lever (silt) or at high water content (clay)

Neutron radiography imaging - evaporation



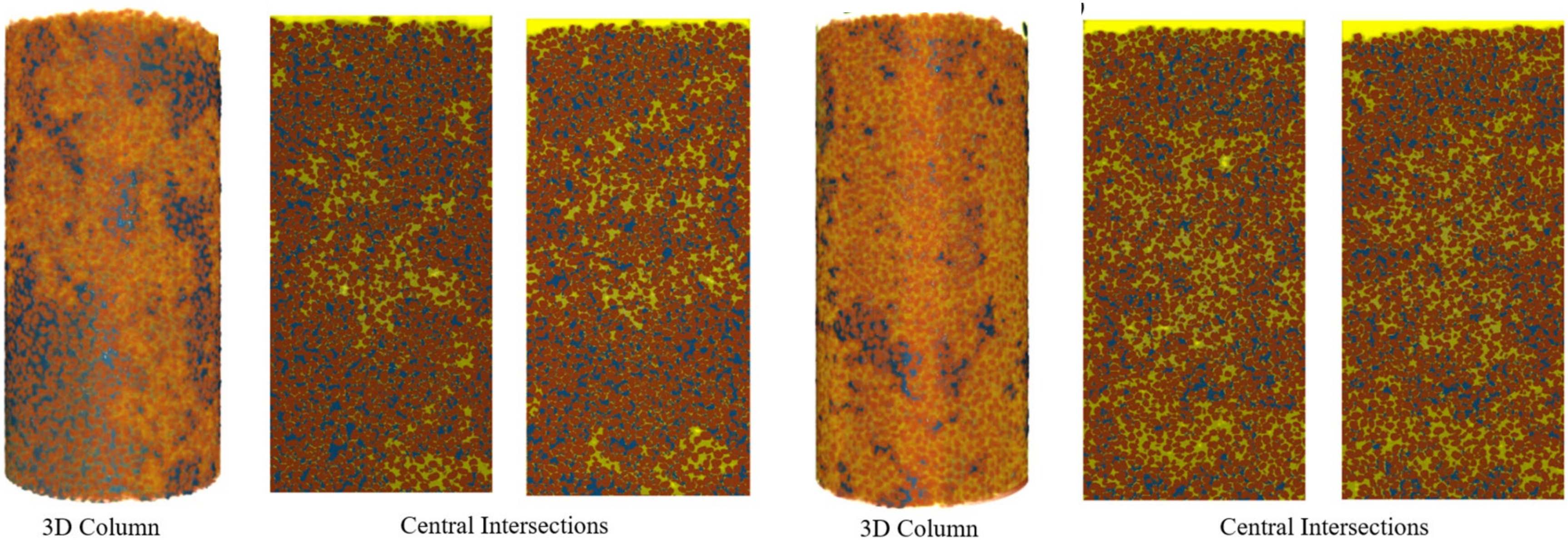
Water content: high → low
medium

Slower evaporation from treated samples compared to controls (~ 8 h evaporation)

Water distribution during evaporation: X-ray tomography

UD1022-Treated sample

Control sample



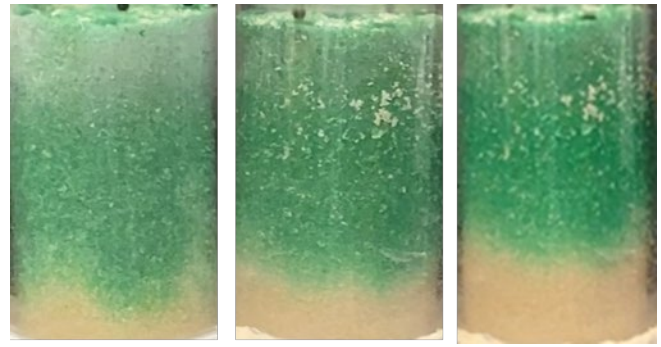
Brown - sand particles; yellow - air; blue - water

(Zeng et al., in prep)

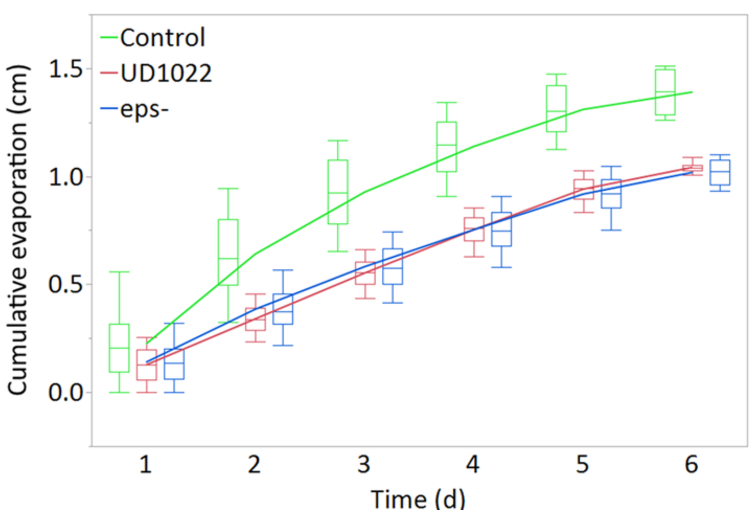
- The images were taken at a similar water content (control: 25.7%; treated: 25.3%)
- Water distribution in the treated sample is **heterogeneous** with water 'lumped' together (more visible blue 'spots')
- Water distribution is **more uniform** in the control sample with thinner water films (less visible)

Effect of UD1022 and eps- on infiltration and evaporation

Infiltration profile



control **UD 1022** **eps-**

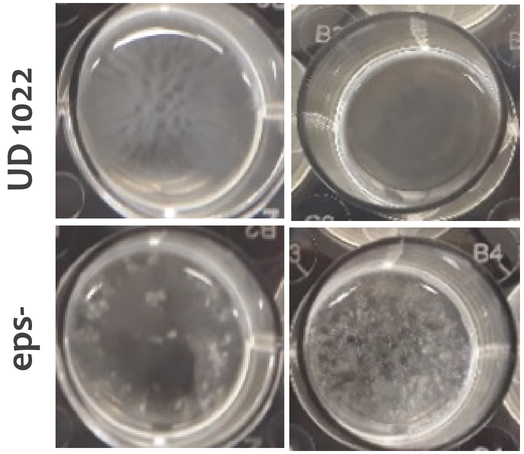


- Both UD1022 and eps- treated samples held more water and the water was more heterogeneously distributed in treated samples;
- Both UD1022 and eps- reduced evaporation;
- Why the eps- mutant had similar effects as EPS-producing UD1022?

(Kaniz et al., in prep)

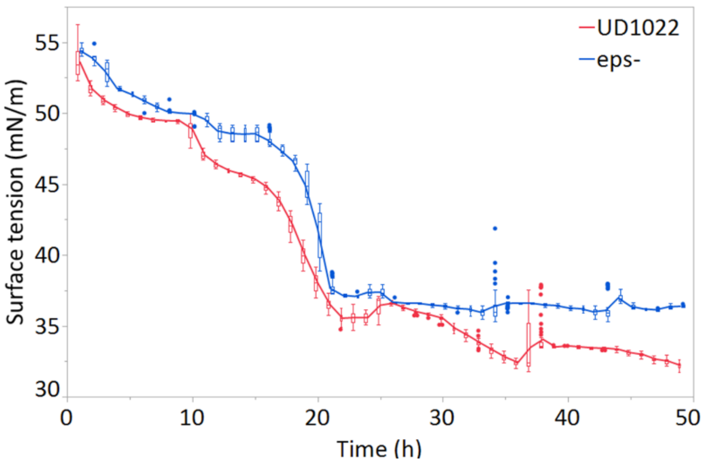
Properties of UD1022 and eps-

(Kaniz et al., in prep)

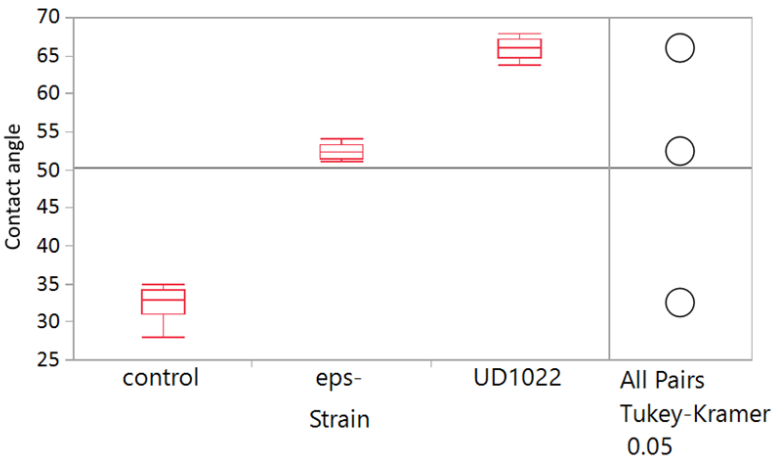


Continuous, dendritic and thin pellicles

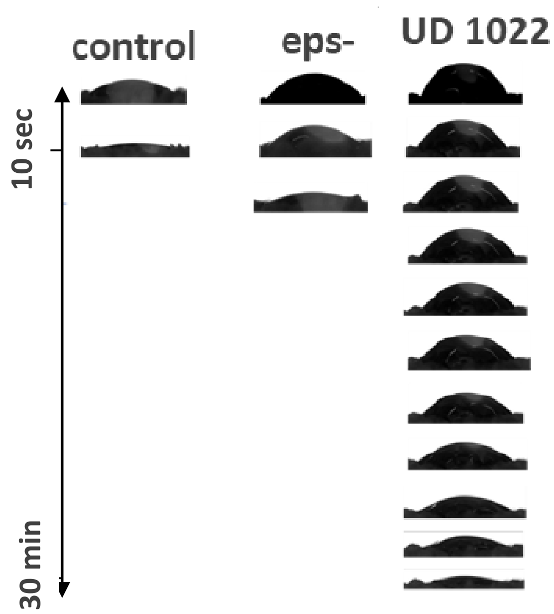
Discrete and thick pellicles



UD1022 and eps- reduced surface tension to similar values



Both strains increased contact angle



Water droplet spreading slowest on UD1022-treated sand layer

What are the factors/mechanisms?

Table 1. Physical properties of extracellular polymeric substances (EPS) and mucilage and their effects in soil.

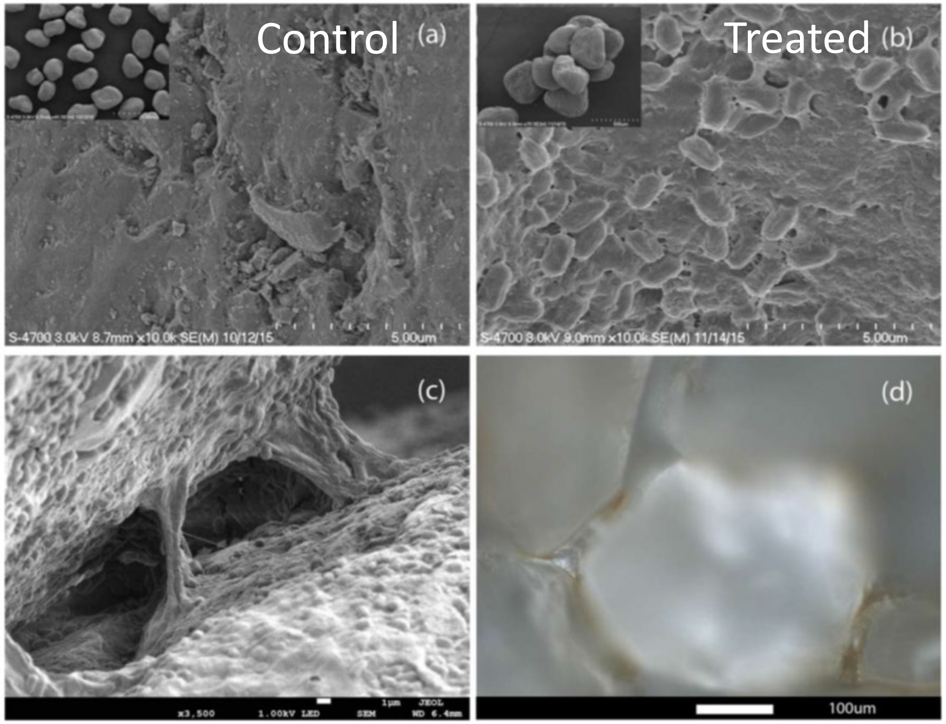
Property or effect	Bacterial EPS	Root mucilage	Seed mucilage
	Intrinsic properties		
Increased viscosity and viscoelasticity	Körstgens et al. (2001), Stoodley et al. (2002), Wloka et al. (2004), Shaw et al. (2004), Lieleg et al. (2011)	Read and Gregory (1997), Naveed et al. (2017)	Naveed et al. (2017)
Decreased surface tension	Raaijmakers et al. (2010) and references included	Read and Gregory (1997), Read et al. (2003)	Naveed et al. (2018)
Adsorption of water	Roberson and Firestone (1992), Flemming et al. (2016)	McCully and Boyer (1997), Read et al. (1999)	Segura-Campos et al. (2014)
	Effect on soil hydraulics		
Increased soil water retention	Roberson and Firestone (1992), Chenu (1993), Rosenzweig et al. (2012), Volk et al. (2016)	this study (maize mucilage in glass beads, Supplemental Fig. S1)	Kroener et al. (2018); this study
Slowed down evaporation from soil	Chenu (1993), Flemming (2011), Deng et al. (2015), Zheng et al. (2018), Adessi et al. (2018)	–	this study
Increased relative hydraulic conductivity†	Volk et al. (2016), Zheng et al. (2018)	–	this study

† The relative hydraulic conductivity is defined as the hydraulic conductivity divided by the saturated hydraulic conductivity. This means changes in hydraulic conductivity during drying of soils are eased.

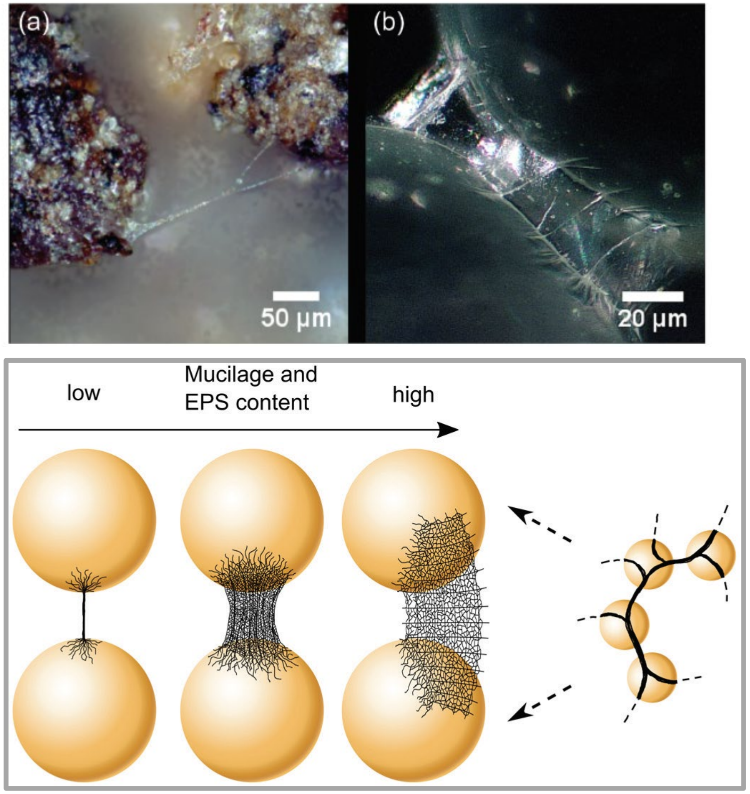
(Benard et al., 2019)

- EPS/mucilage has large water holding capacity
- EPS/mucilage modifies pore structures
- EPS/mucilage increases pore-water viscosity
- EPS/mucilage lowers pore-water surface tension

Mechanisms – viscosity and surface tension effects



Samples treated with *UD1022* *(Zheng et al., 2018)*



(Benard et al., 2019)

- Bacteria cells and EPS cover the sand surface and “glue” sand particles together;
- High viscosity EPS form inter-connected filaments in soil matrix → increase water retention and reduce saturated hydraulic conductivity;
- Reduced surface tension decreases capillary rise → reduce evaporative flux.

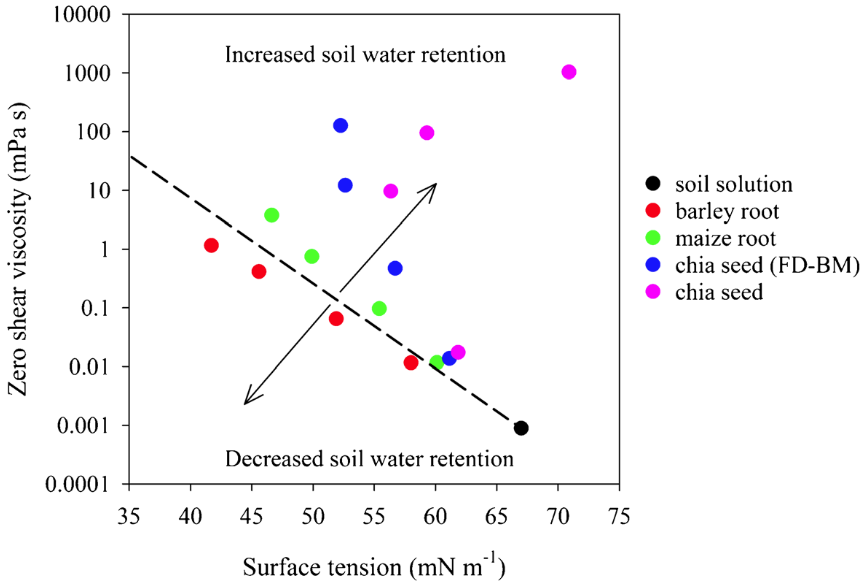
Interplay between viscosity and surface tension effects

Ohnesorge number:

(Ohnesorge, 1936)

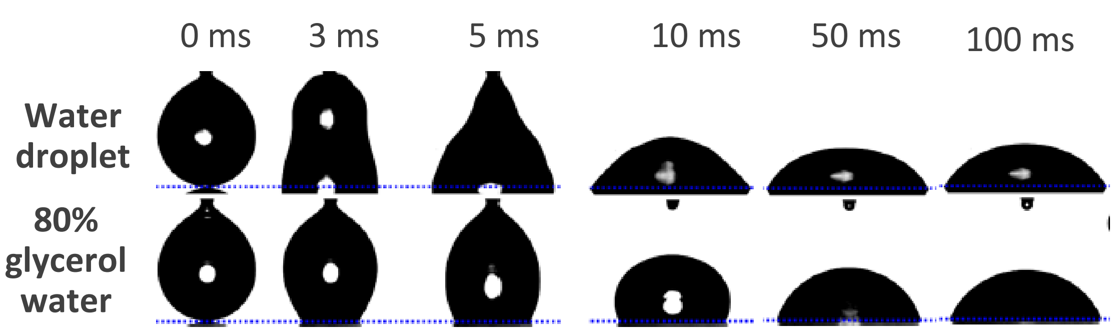
$$\mathrm{Oh} = \frac{\mu}{\sqrt{\rho \sigma r}}$$

- Viscosity dominates over inertia and surface tension when Oh >> 1
- EPS/mucilage can exhibit behaviors of surfactants (drying at smaller suctions) as well as hydrogels (holding more water etc.)



(Naveed et al., 2019)

- EPS/mucilage can reduce contact angle and affect wetting



(Chen and Bonaccurso, 2014)

Summary and implications

- Both UD1022 and its mutant eps- can reduce evaporation rate and infiltration depth, resulting in increased water retention;
- Water distribution is more heterogeneous (e.g., with more disconnected water 'pockets') in treated samples compared with the controls where water is more uniformly distributed (e.g., as thin films);
- EPS production/biofilm formation is the main reason for the observed effects due to its ability to 1) adsorb water, 2) forms filaments and inter-pore structures, 3) increase viscosity and 4) decrease surface tension of soil solution;
- (But eps- mutant with inhibited EPS production had similar effects as UD1022. Why?)
- Rhizobacteria have the potential to increase green water availability and use efficiency (making ***more*** water available for ***longer*** time to plants);
- Rhizobacteria are a largely ***untapped*** underground ***resource*** and could potentially be used for building productive rhizospheres.