Patterns in the rhizosphere microbiome that lead to improved plant growth

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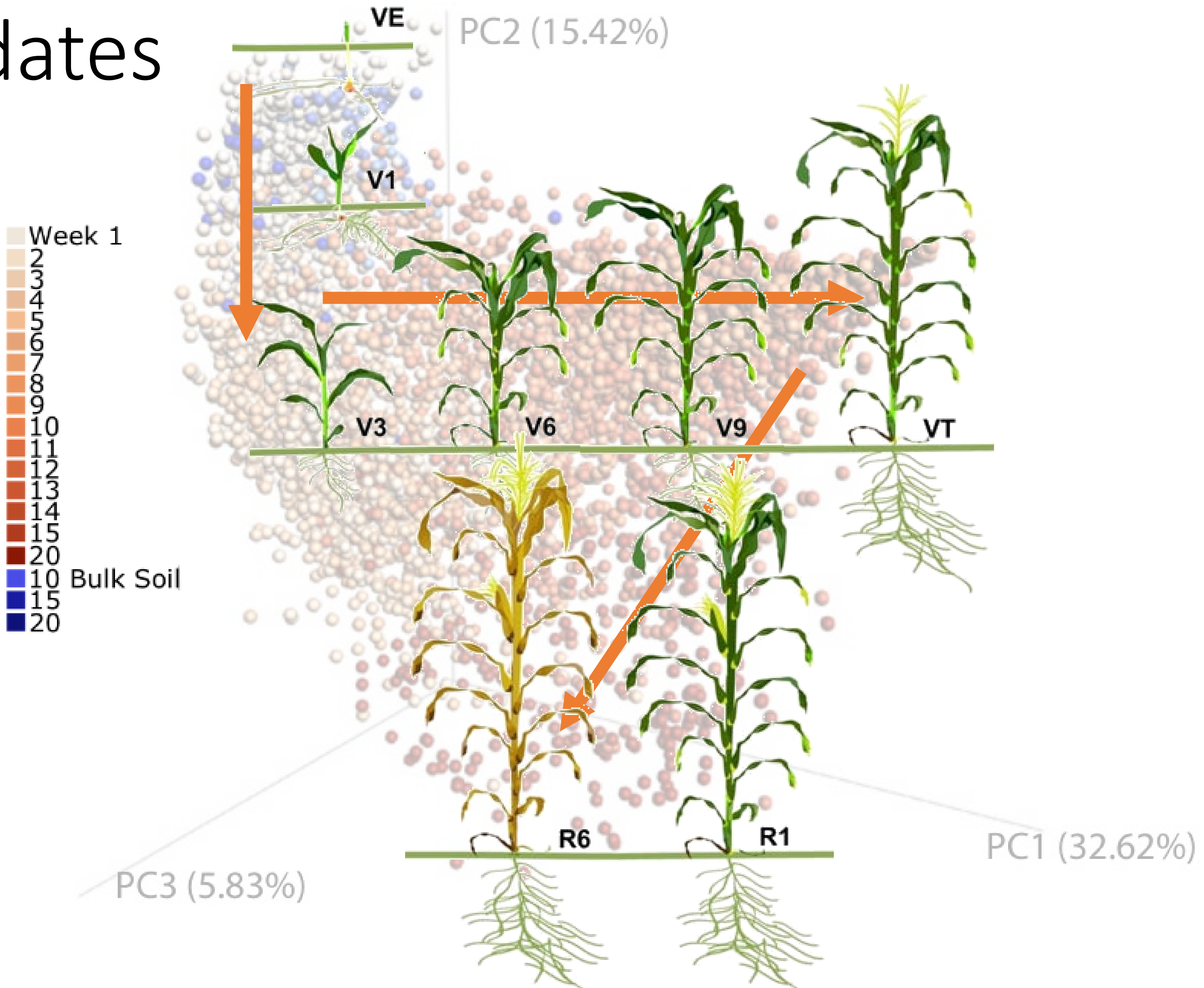
Role of plant exudates

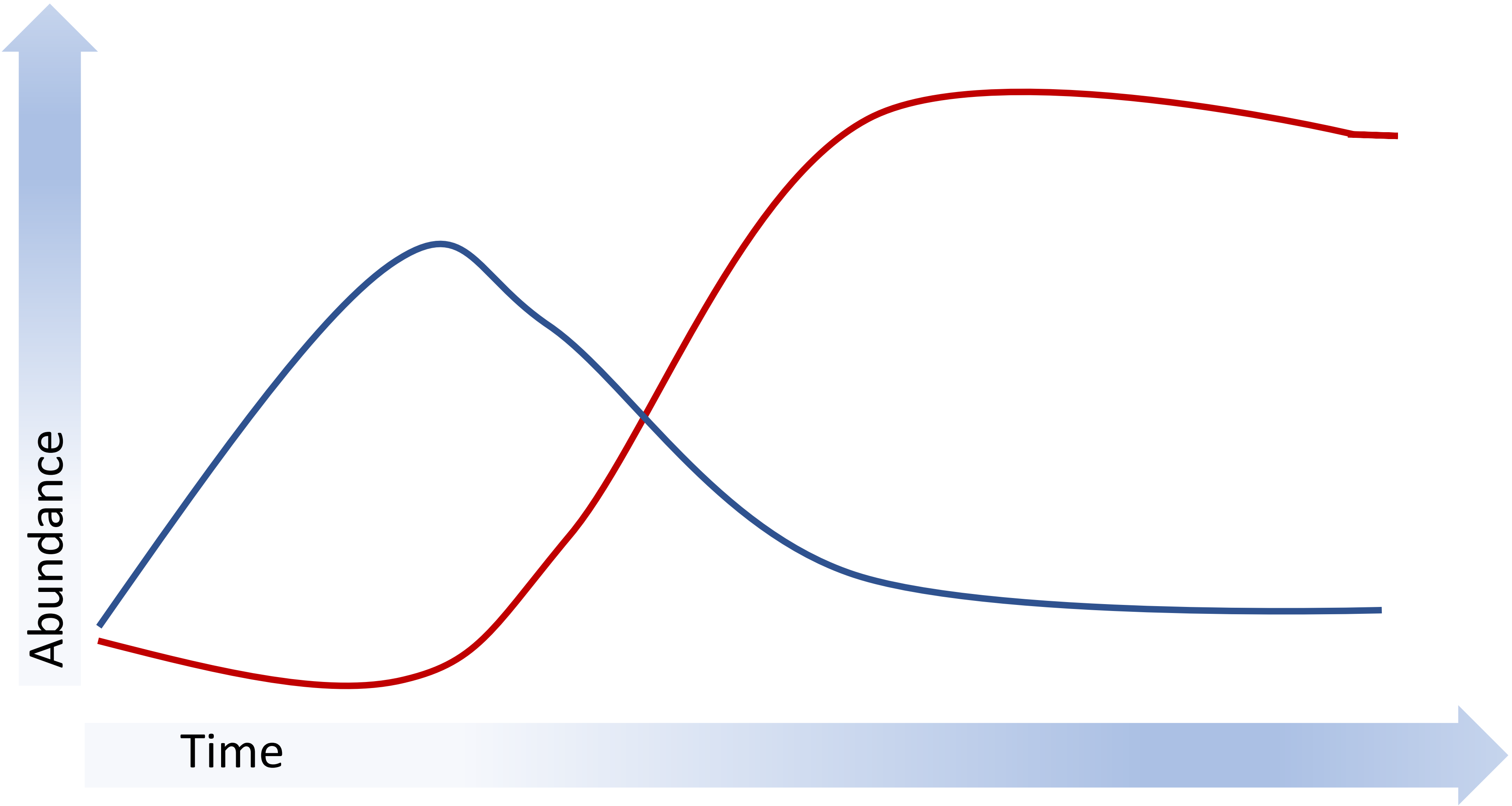
"Root exudation clearly represents a significant carbon cost to the plant (Marschner 1995), with young seedlings typically exuding about 30–40% of their fixed carbon as root exudates (Whipps 1990)."

Badri, D. V., & Vivanco, J. M. (2009). Regulation and function of root exudates. *Plant, cell & environment*, *32*(6), 666-681.



Walters *et al.* 2018.
Large-scale replicated field study of maize rhizosphere identifies heritable microbes
PNAS 115 (28) 7368-7373
Adapted by Nathan Cude

Rhizobia in the Corn Rhizosphere



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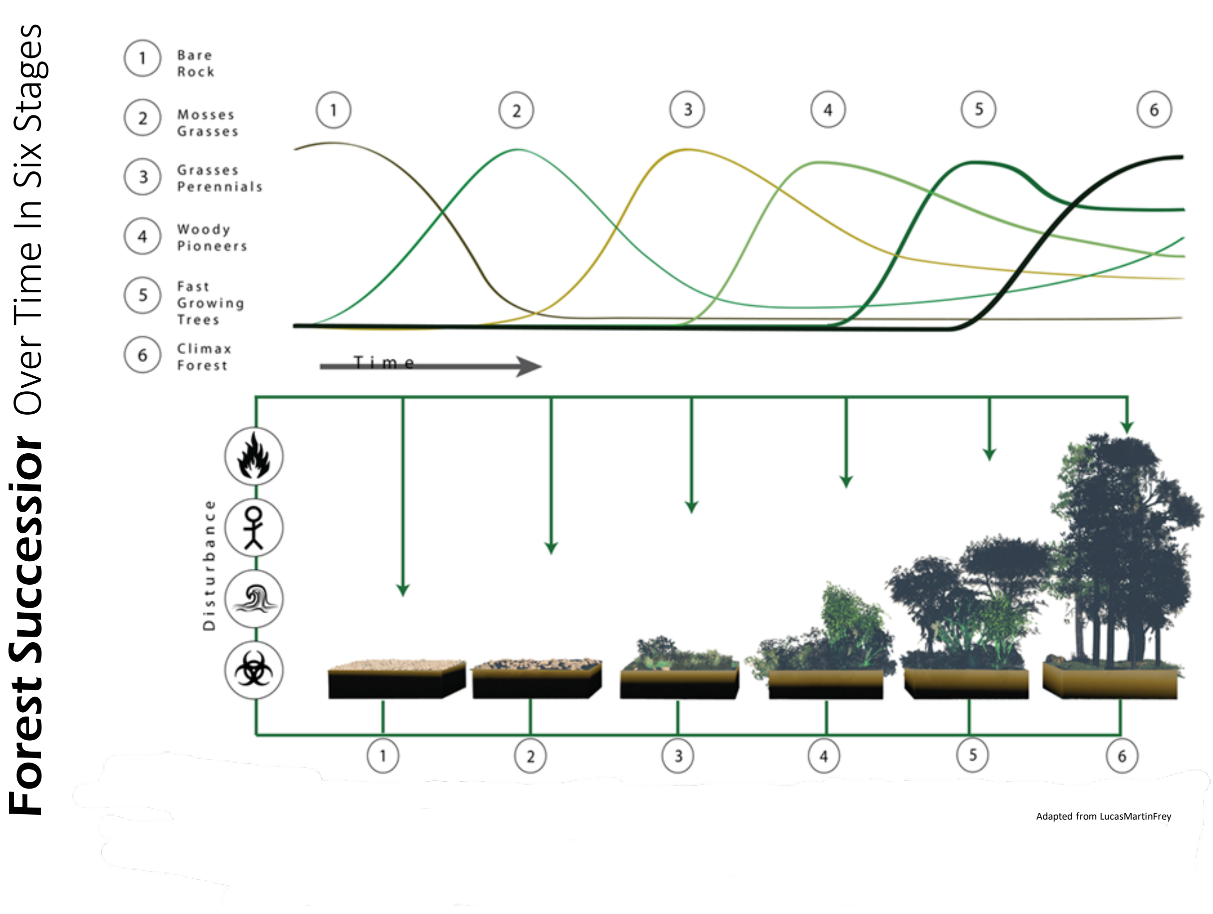
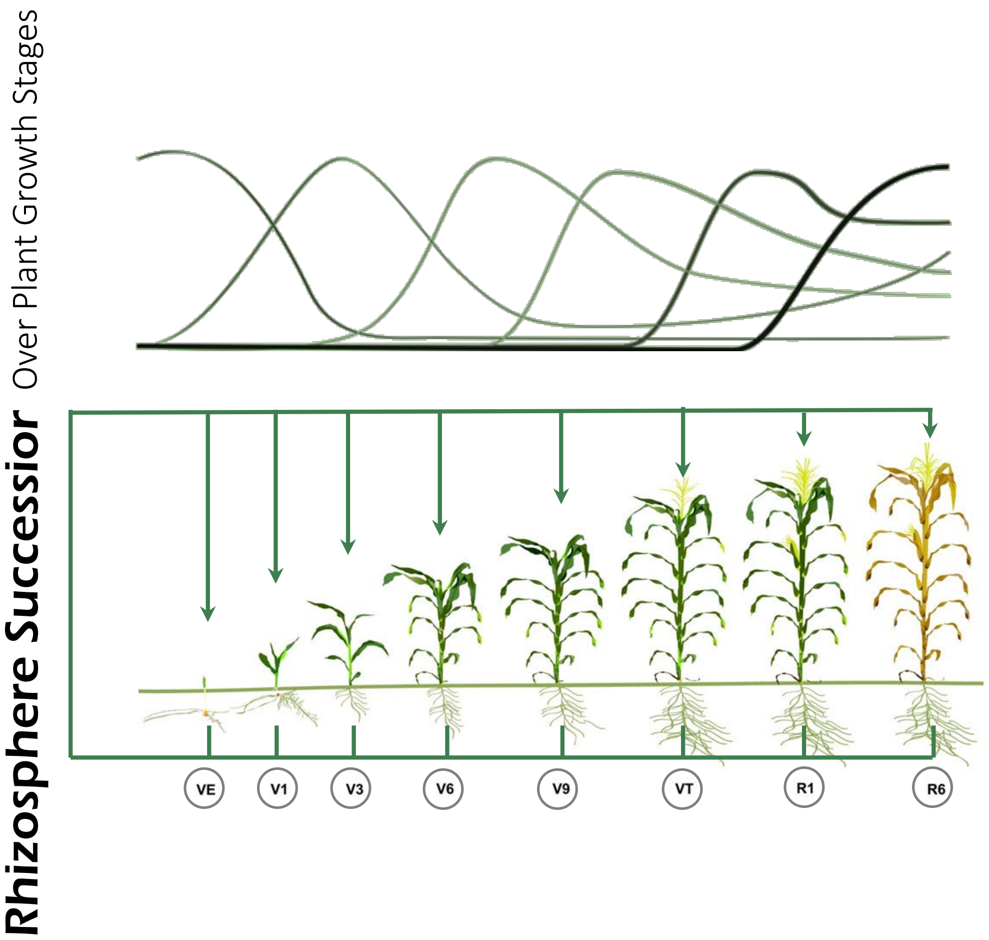
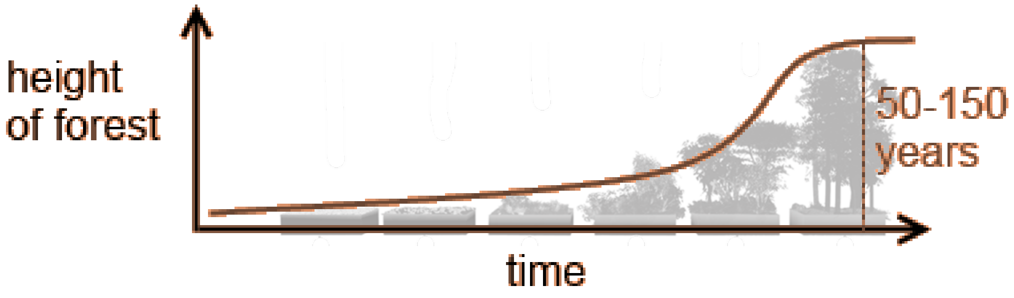
Microbial Succession in the Rhizosphere



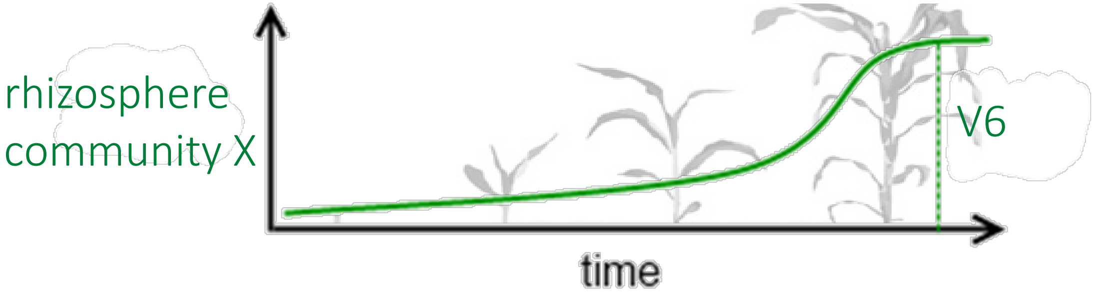


Microbial Succession in the Rhizosphere

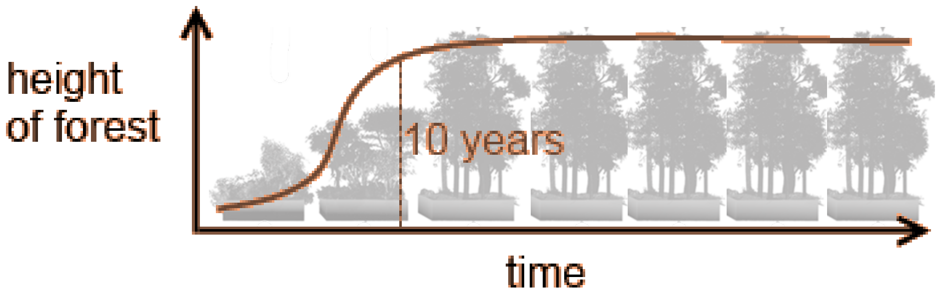
Naturally Growing Forest



Natural Rhizosphere Community

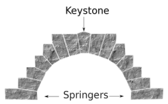


Accelerated Forest Succession



Seeding the ecosystem with pioneering species accelerates succession

deepgreenpermaculture.com



H_0: Seeding the rhizosphere with pioneering species accelerates succession

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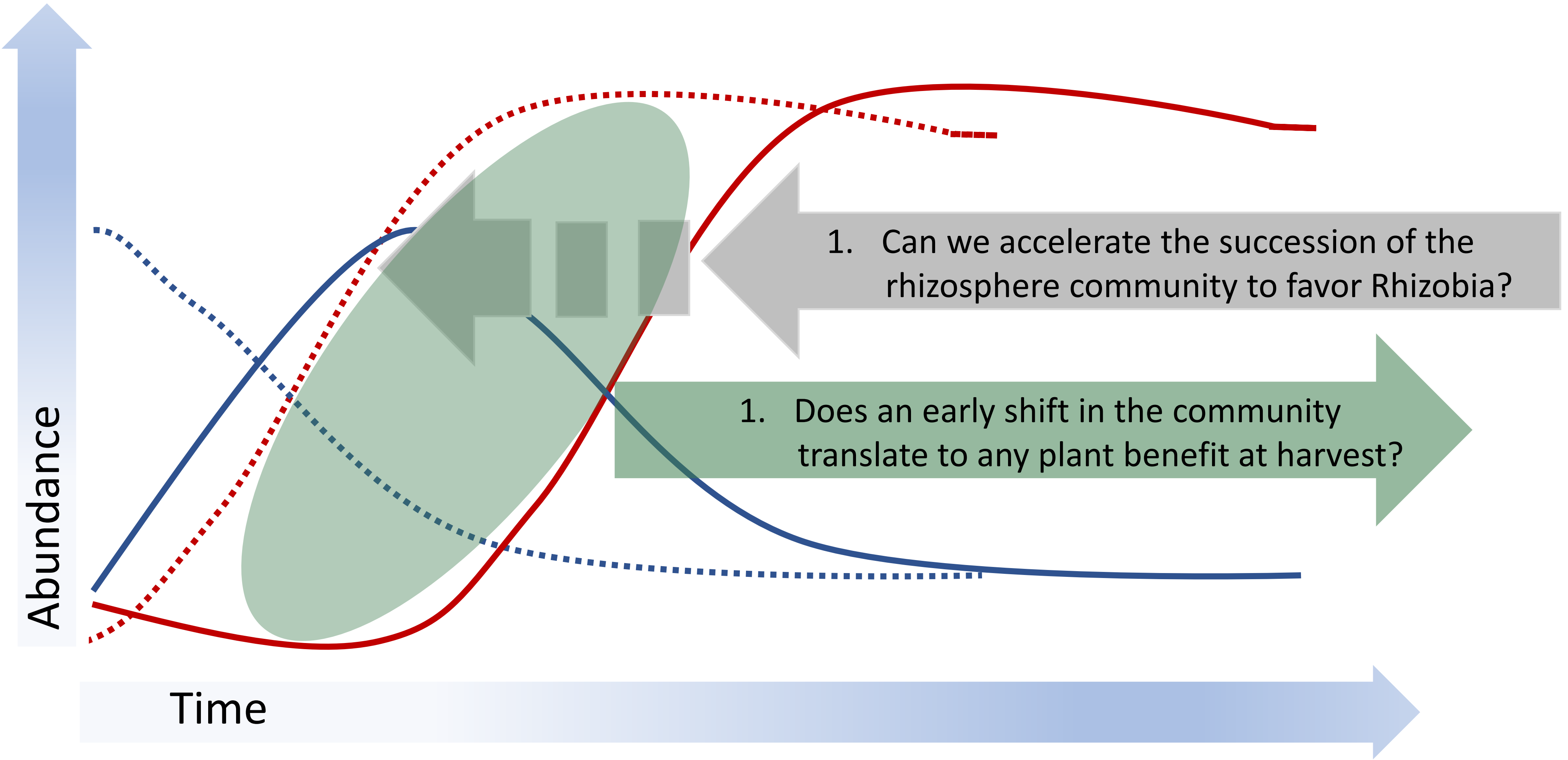
Rhizobia in the Maize Rhizosphere



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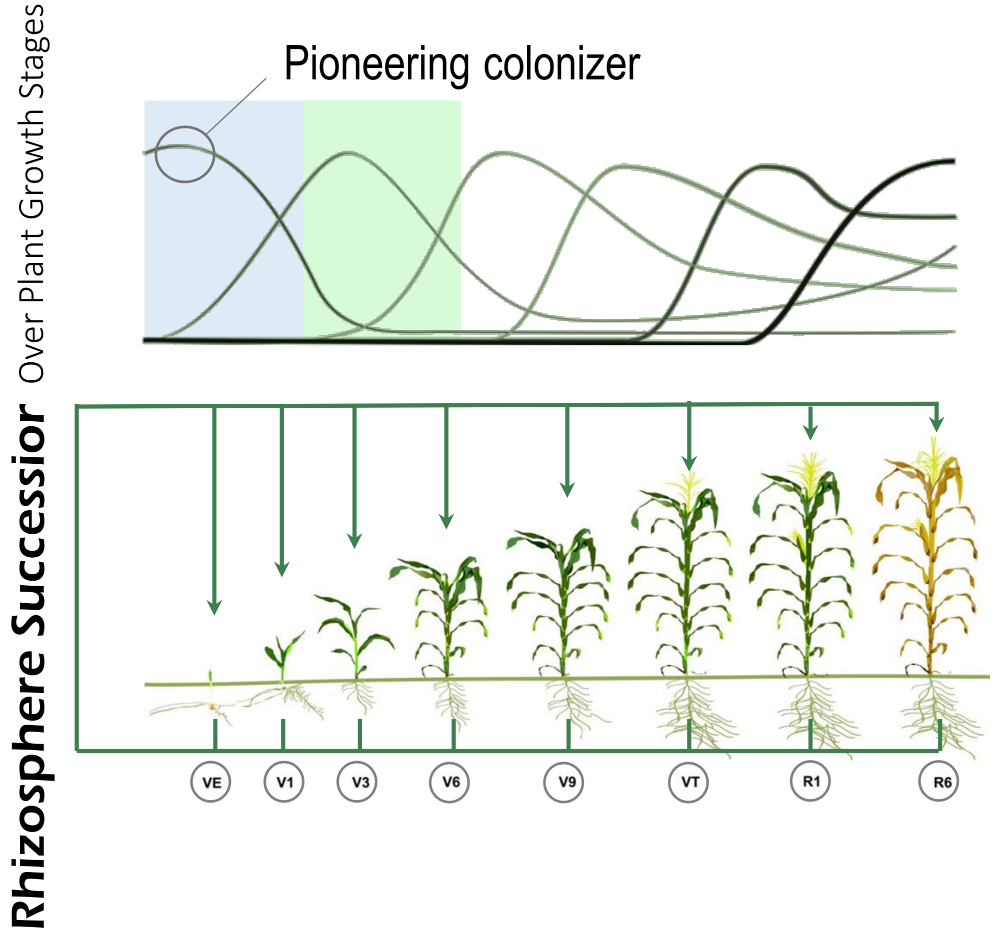
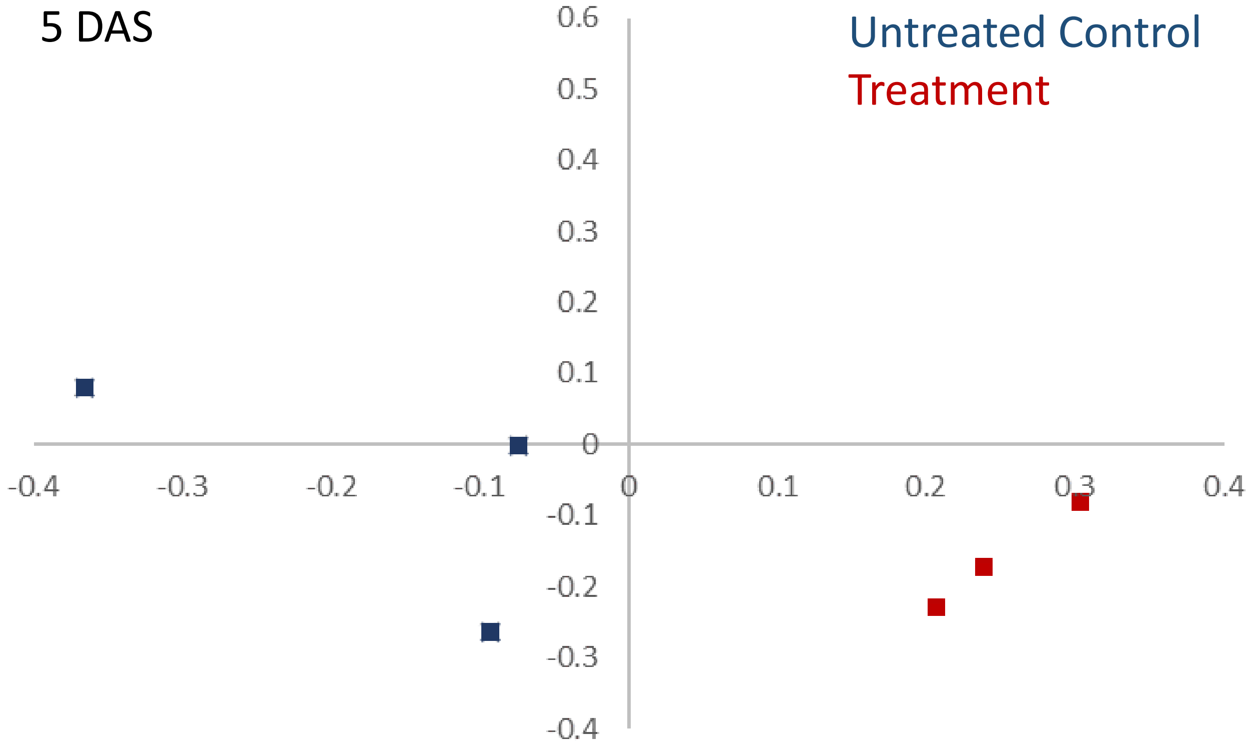
Microbial Succession in the Rhizosphere





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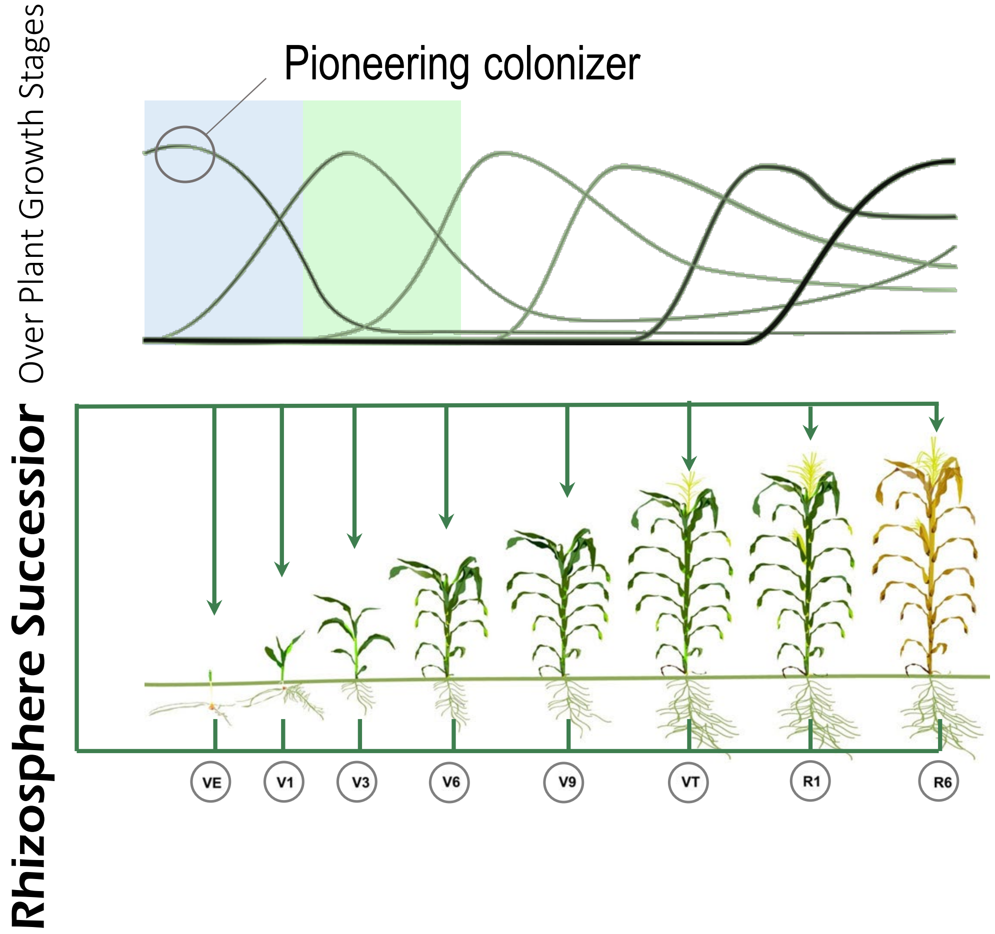
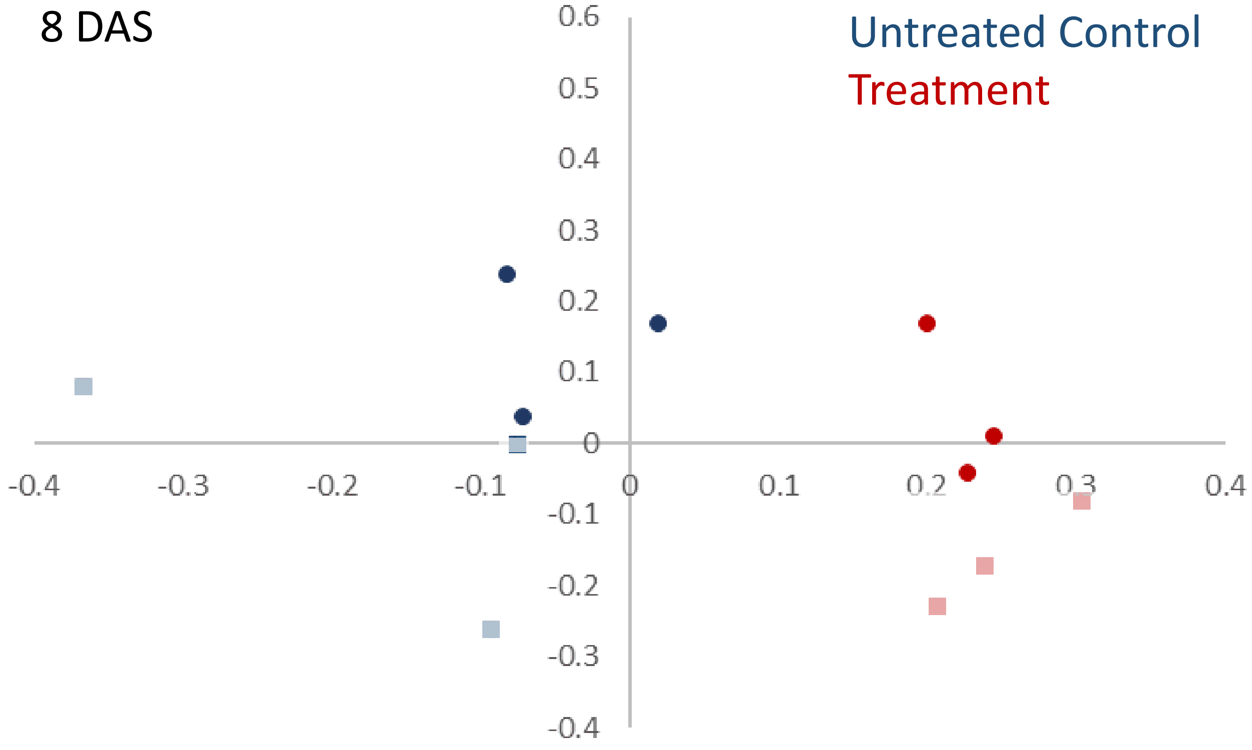
Microbial Succession in the Rhizosphere





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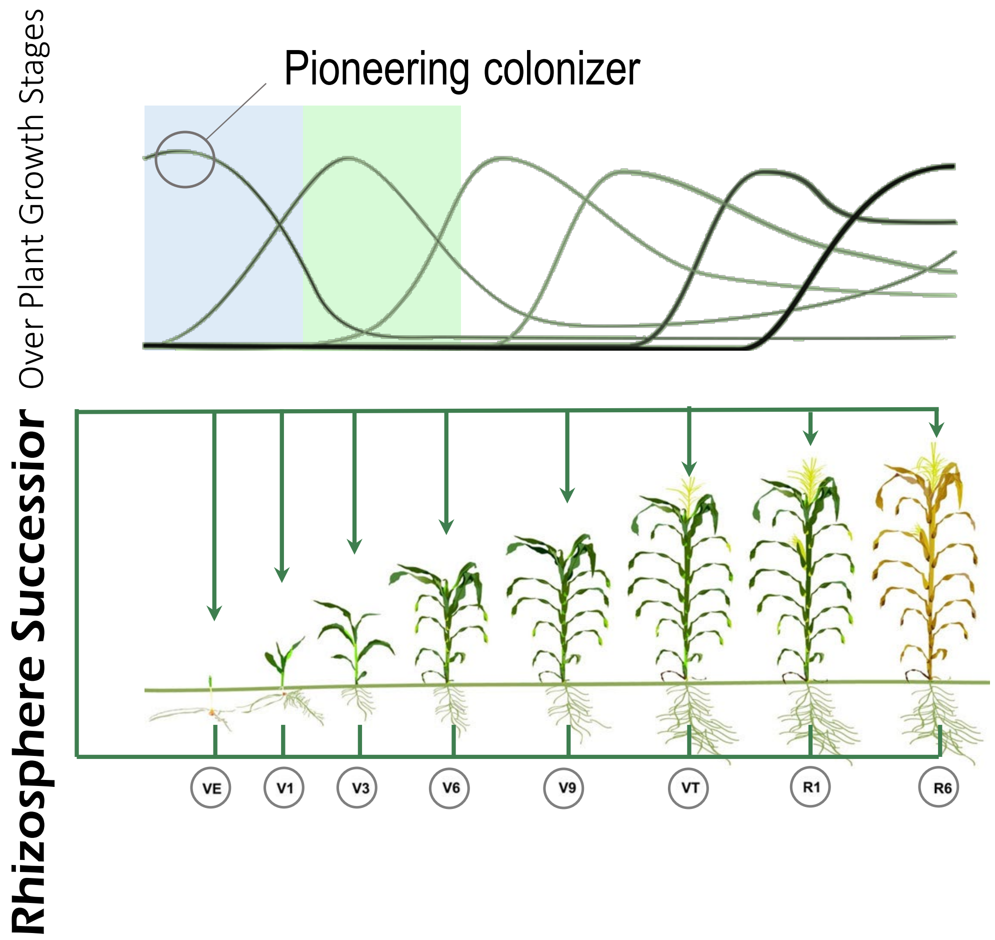
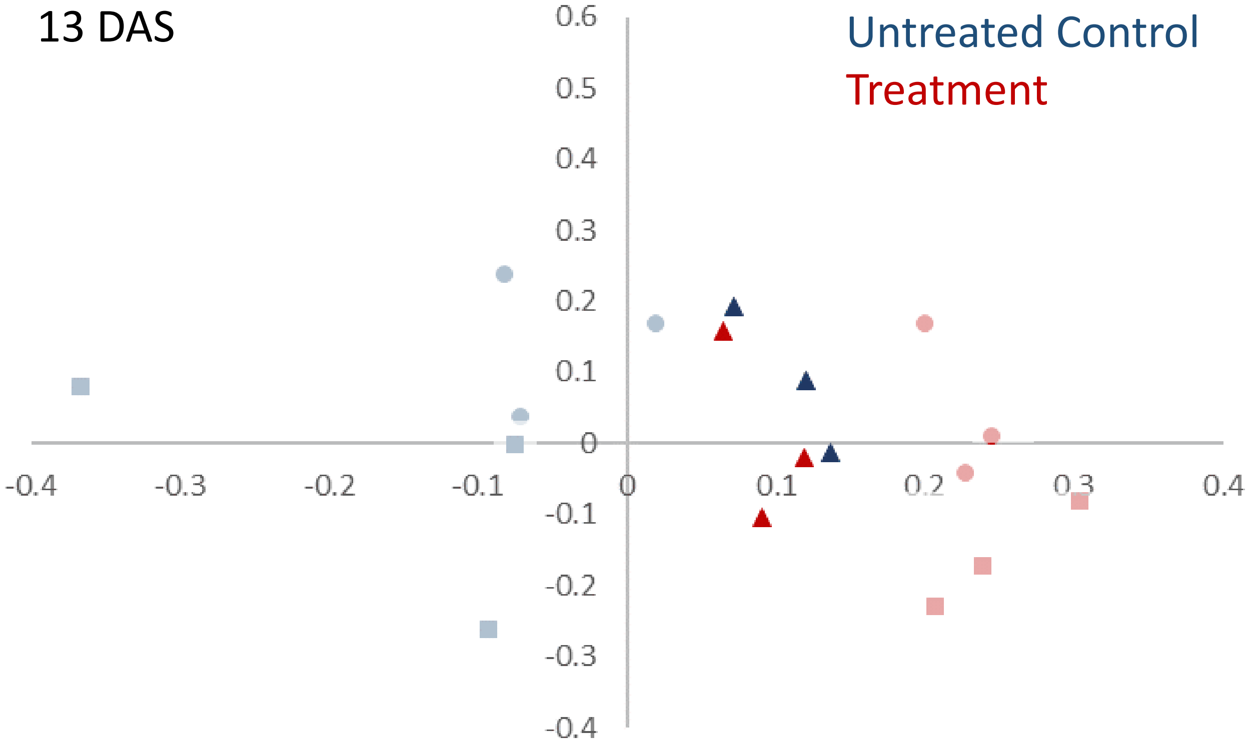
Microbial Succession in the Rhizosphere





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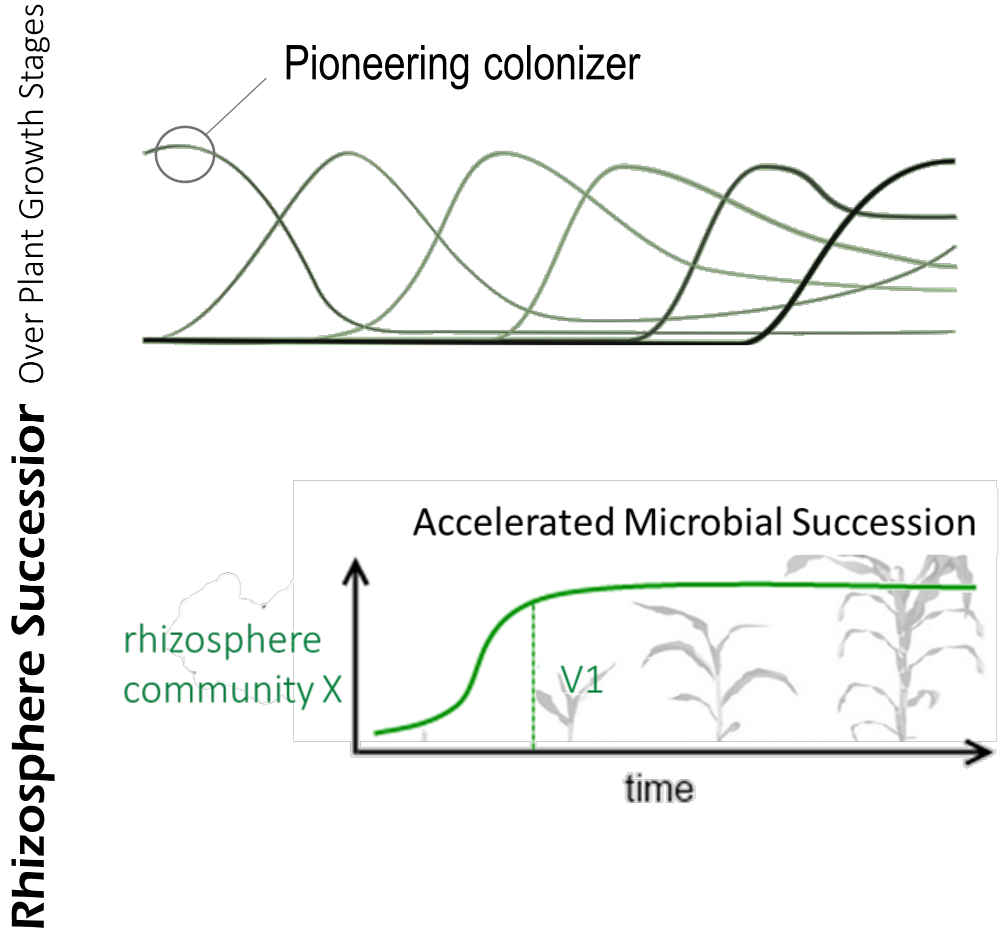
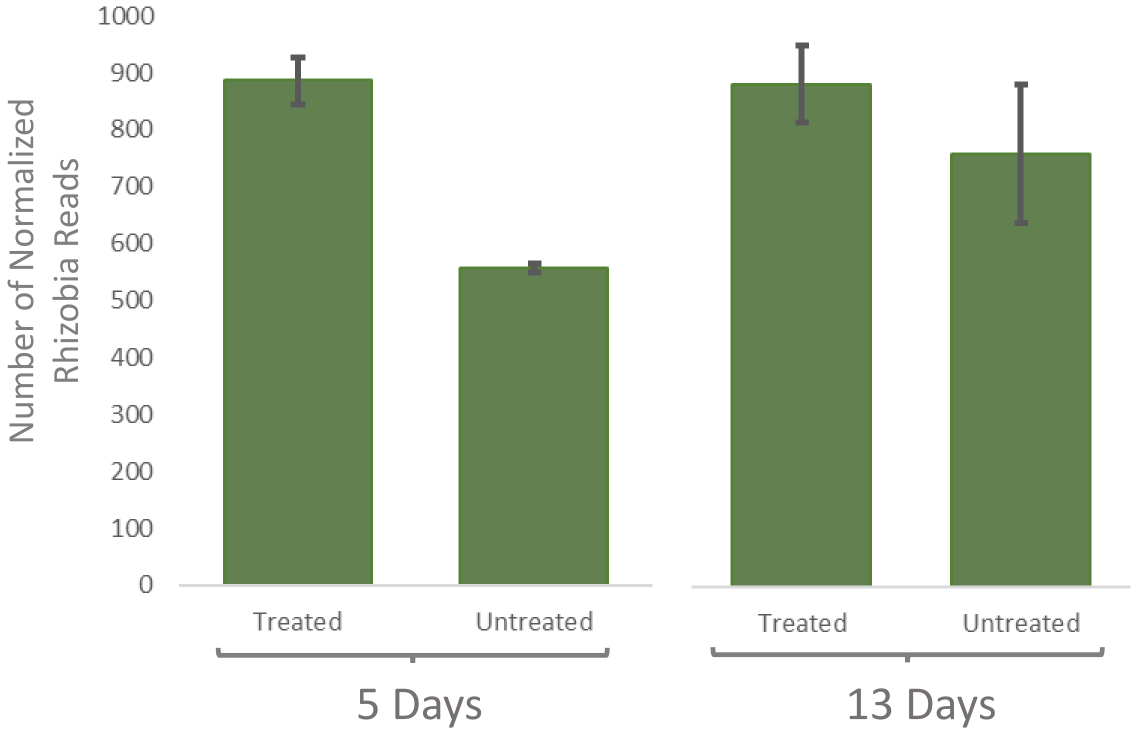
Microbial Succession in the Rhizosphere





Result: We see a significantly higher number of reads corresponding to Rhizobia at early growth stage when inoculated with Pioneering colonizers.

Conclusion: We can accelerate succession to favor Rhizobia by inoculation with pioneering colonizers.

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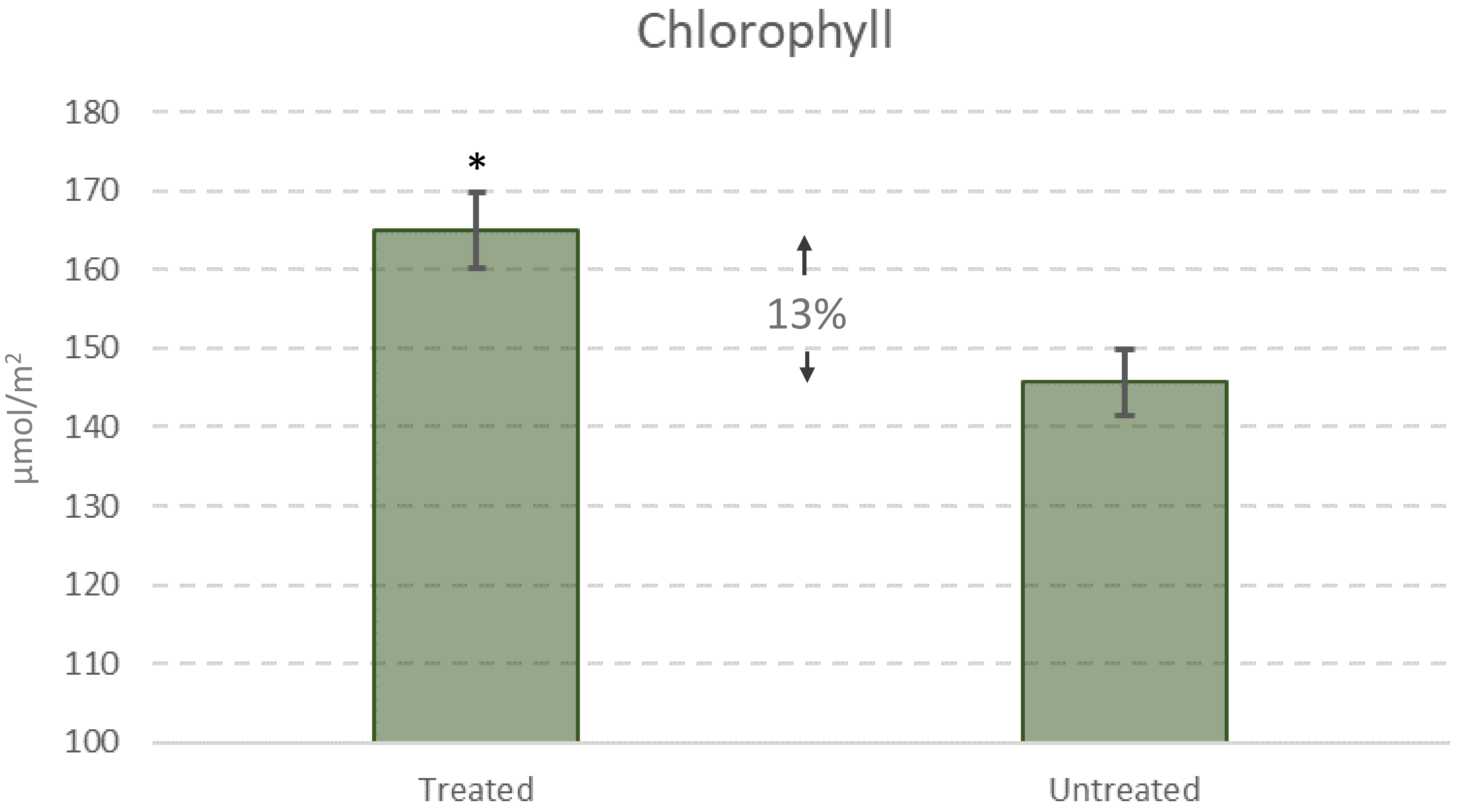
Greenhouse Trials

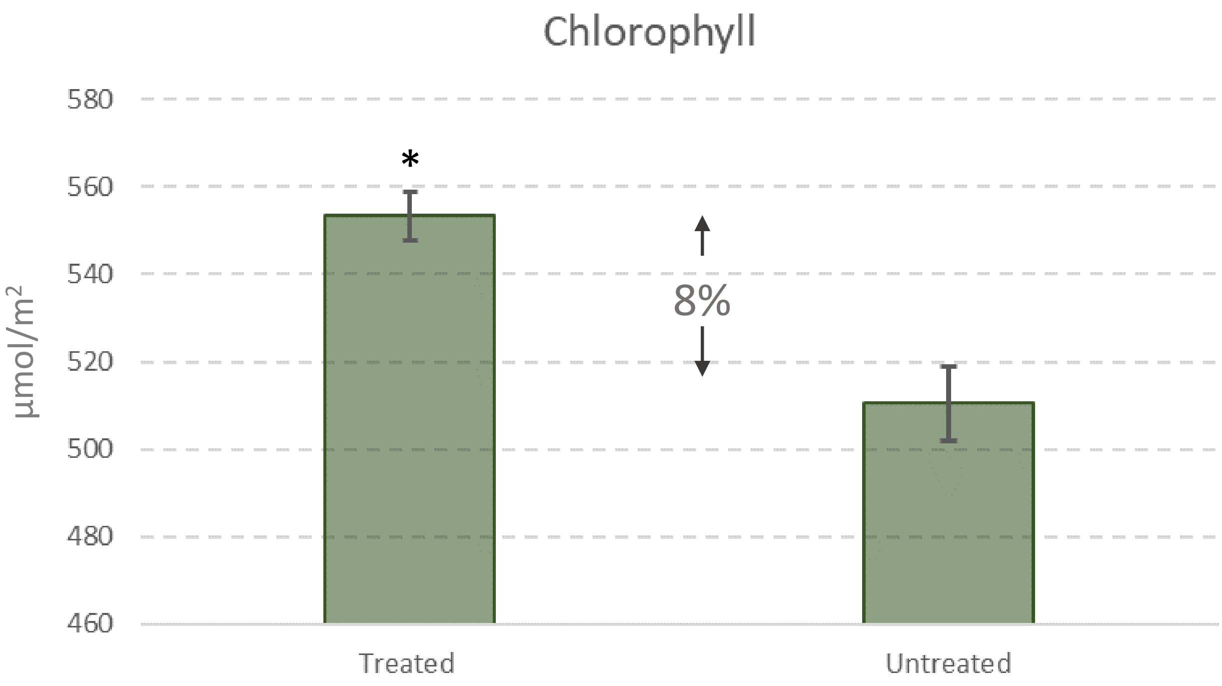
Chlorophyll content has a strong correlation to plant nitrogen content, due to the investment of nitrogen in chlorophyll molecules

Sage, RF., et al. *Plant physiology* 85.2 (1987): 355-359.

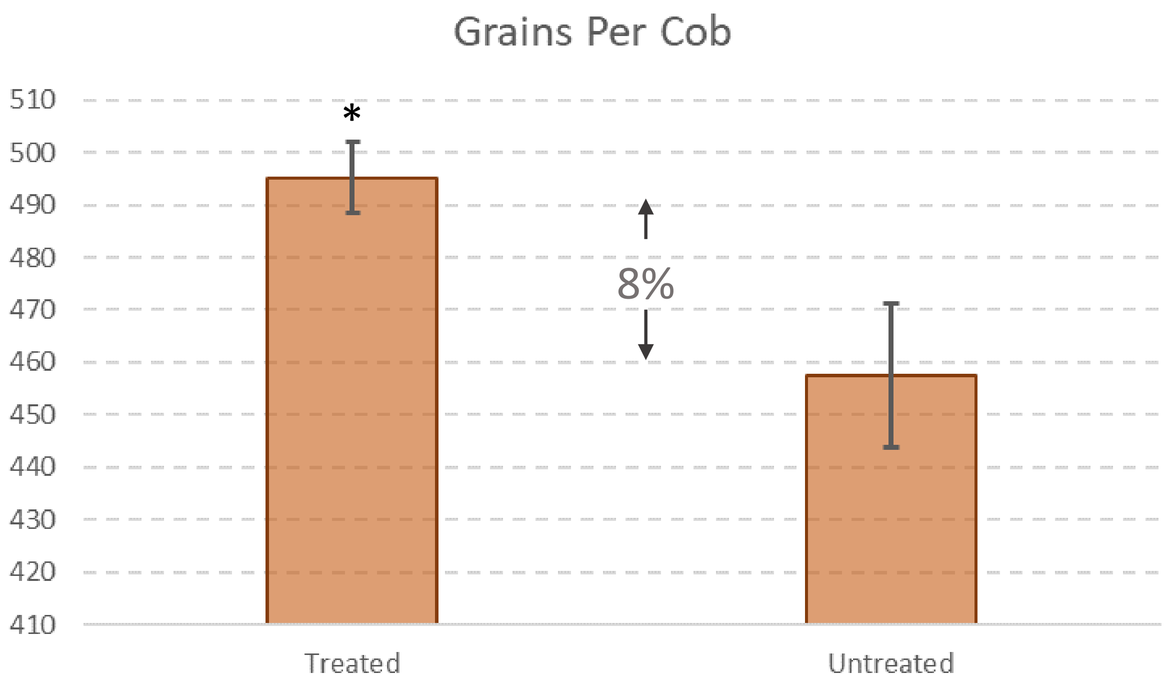


Mean chlorophyll content of corn plants grown in a greenhouse comparing seeds inoculated with pioneer colonizer (Treated), and seeds inoculated with growth media (Untreated). Error bars represent S.E. ($p < 0.05$, N = 15)

Microplot Field Trial Results



Mean chlorophyll content of corn plants grown in microplot field trials comparing seeds inoculated with pioneer colonizer (Treated), and seeds inoculated with growth media (Untreated). Error bars represent S.E. ($p < 0.1$, N = 90)



Mean number of grains per cob of corn plants grown in microplot field trials comparing seeds inoculated with pioneer colonizer (Treated), and seeds inoculated with growth media (Untreated). Error bars represent S.E. ($p < 0.1$, N = 135)

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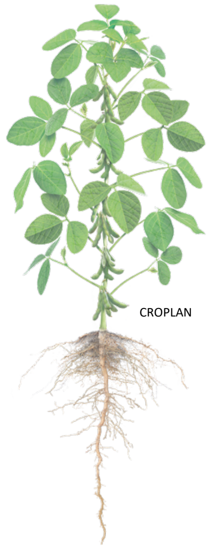
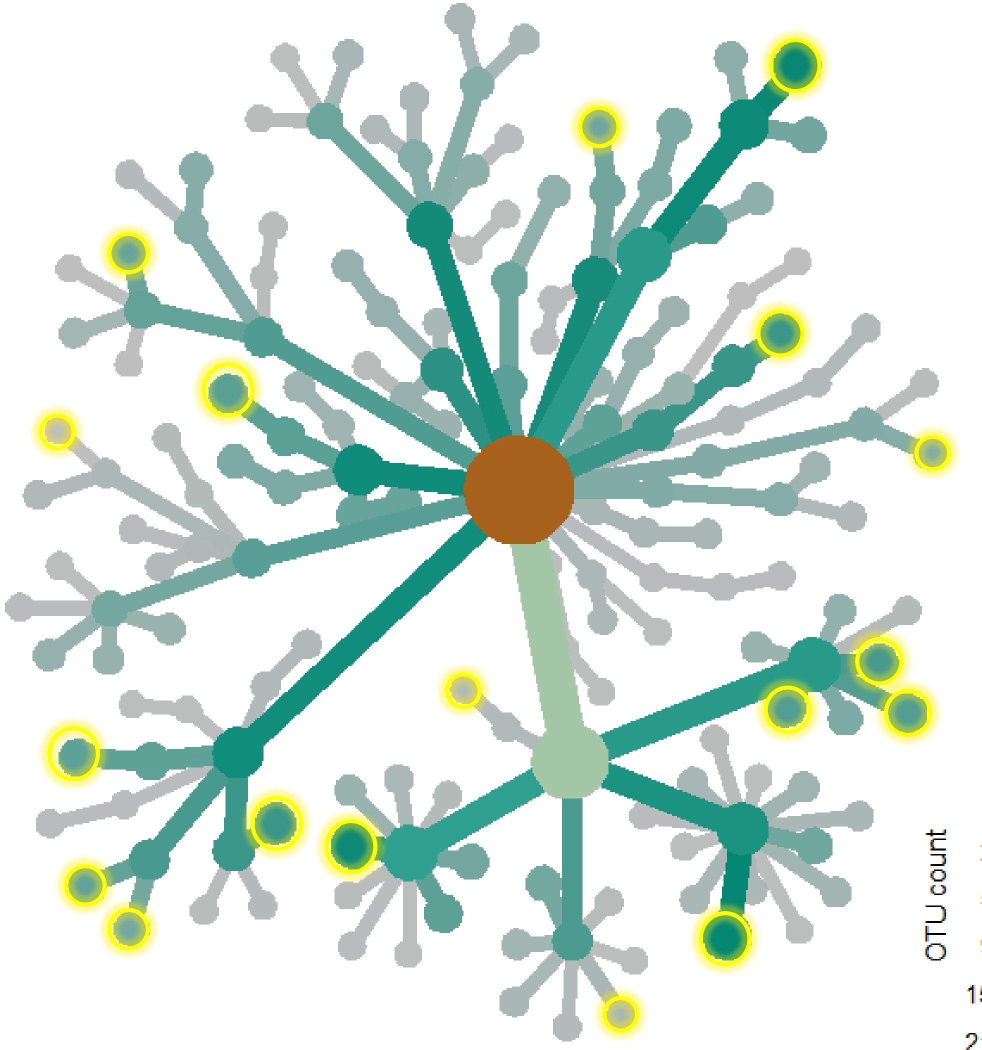
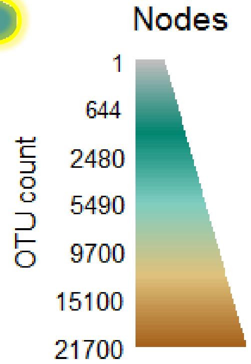
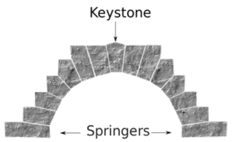
Example Two: Soybeans

Keystone Functional Traits in the Rhizosphere









Identification of Functional Traits that significantly enriched in the rhizosphere, but are not linked to phylogeny

X^2	Enriched	Not Enriched	Sum
Function +	10	14	24
Function -	5	70	75
Sum	15	84	99

p-value = 0.000032

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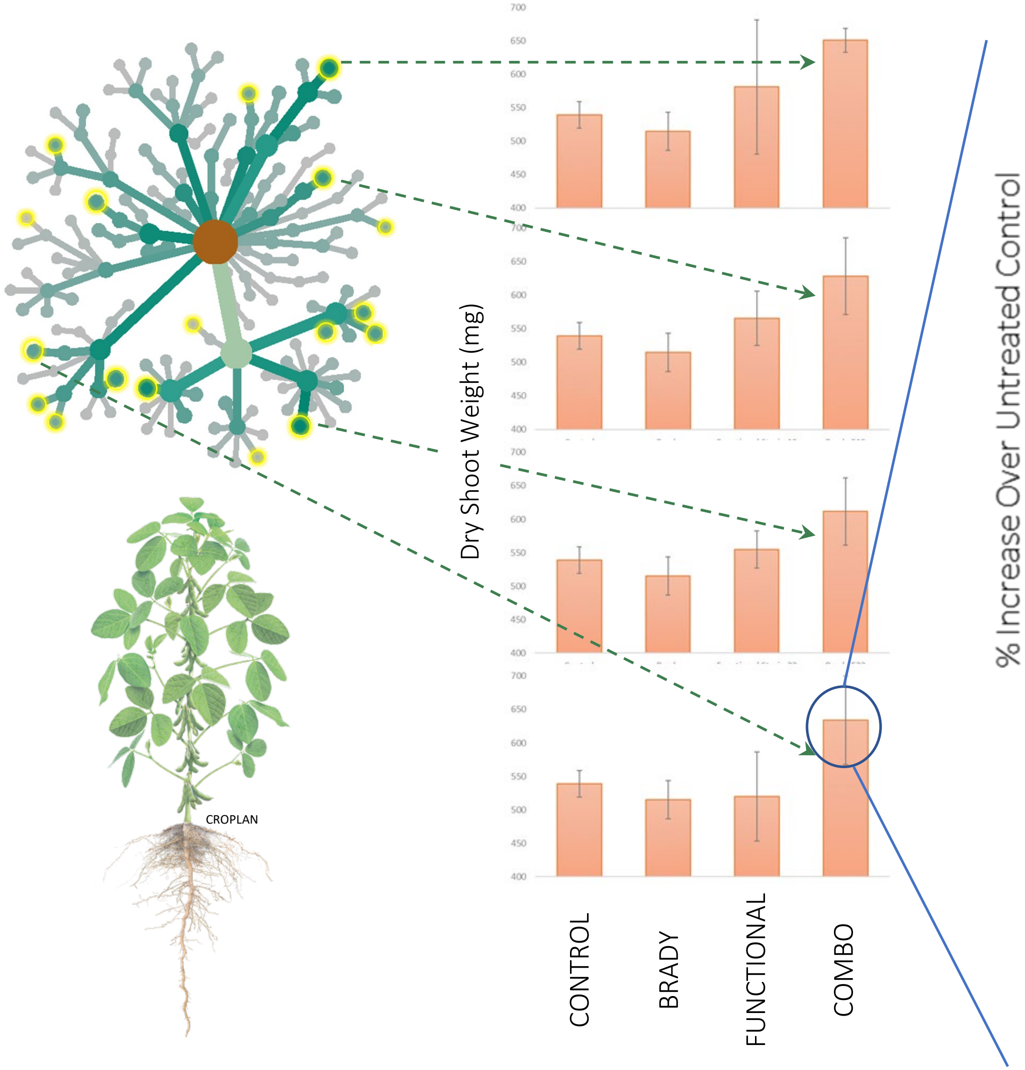
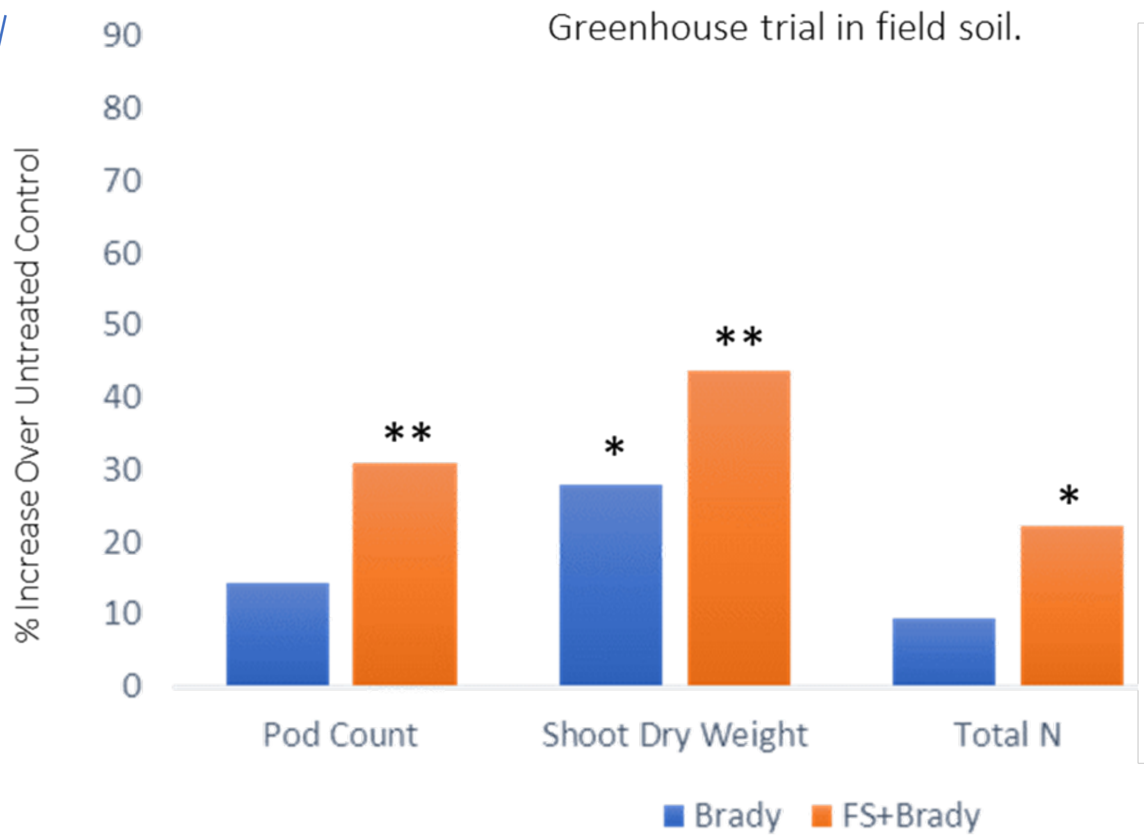
Keystone Functional Traits in the Rhizosphere





* $p < 0.05$ compared with Control
** $p < 0.01$ compared with Control

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Selection and Evaluation of Biological Products in the Field

MOA

- Understanding how the organism/active operates
- Identifying sites and controlling sites that benefit from the MOA
- Determining if there are other factors that determine the initiation, duration or intensity of the product performance

Environment

- Replicating assay, growth chamber and greenhouse conditions for broad scale testing
- Minimizing outside weather conditions that are necessary for product performance (temperature, moisture, fertility and pests)
- Identifying interactions with the soil and plant biomes with the product

Crop Physiology

- Delivering a viable product to the field in high enough concentrations to perform as expected
- Identifying the proper timing of application to maximize the benefit to the MOA
- Monitoring the interaction of the plant to the product (antagonism, symbiosis or neutral)

Mode-of-Action

Biological

- MOA is likely a symbiosis where the biological contributes to overcoming a imitating factor in the plant
- Evaluation needs to include the expression of the MOA as well as the response on the plant
- Expression/performance of a biological may differ dramatically in different situations and environments
- Application concentration, timings and rates are usually difficult to evaluate due to a possible wide window of responses

Traditional Chemistry

- Often the driving factor is a chemical reaction that can be predicted
- Typically the MOA is a specific timing or location effect that does not change plant physiology
- Response to chemical products is usually more pronounced and consistent
- Concentration is usually determined by cost of production or formulation limitations, so rate is usually the most tested variable

Environment

Biological

- Biologicals tend to be highly affected by the environment as well as other organisms
- The high range of responses in different environments makes repetition less meaningful
- Difficulty in controlling test conditions, especially microorganisms

Traditional Chemistry

- Temperature, wind, humidity and pH can affect placement and performance, but other organisms are less likely to affect negatively
- Physical environmental conditions are easier to control than microbiomes
- Consistent site conditions are easier to locate

Crop Physiology

Biological

- Appropriate application timing and crop stage can limit the performance of many biologicals
- Long term presence of a biological often is determined by a symbiosis with the plant
- Varietal differences may change the interaction of the plant with a biological and increase the development cost of a product and limit the overall usefulness

Traditional Chemistry

- Often target a pest or limiting factor and not directly affecting the plant
- Non-living, so no need of a supporting environment
- Usually varietal differences are less common and less limiting to chemisty

Soil Applied Example

Uncle Ed’s Wonder Biological Starter

- Increases fertility uptake
- Enhances root growth
- Promotes plant vigor
- Higher yield

Testing Evaluation

- Identify which nutrients are targeted and locate fields with a measurable deficiency with soil testing
- Evaluate the local environment physical and biological conditions for the survivability or performance of the biological product
- Monitor the biological concentration from treatment (seed, in-furrow, foliar, etc…) to final placement
- Test the specific MOA expected and ho9w it affects the target crop
- Record soil and air temperature high and lows humidity and rainfall to see how they might influence final yield

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