TESTING THE THEORY OF THE PHENOTYPIC SPECTRUM ON 3-DIMENSIONAL ROOT ARCHITECTURE OF MAIZE

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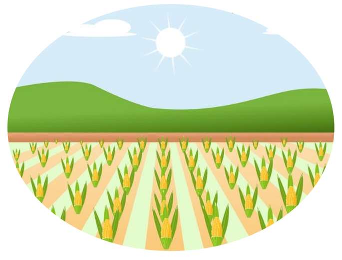
Abstract

Improving root traits to improve efficiency of nutrient uptake in plants is an opportunity to increase crop production in response to climate change induced edaphic stresses. Maize (*Zea mays* L.) studies showed a large variation of root architecture traits in response to such stresses. Quantifying this response uses high-throughput, image-based phenotyping to characterize root architecture variation across edaphic stresses. Our objective is to test if commonly used root traits discriminate stress environments and if a single mathematical description of the complete root architecture reveals a phenotypic spectrum of root architectures in the B73 maize line using manual, DIRT/2D (Digital Imaging of Root Traits) and DIRT/3D measurements. Maize B73 inbred lines were grown in three field conditions: non-limiting conditions, high nitrogen (N), and low N. A proprietary 3D scanner captured 2D and 3D images of harvested maize roots to compute root descriptors that distinguish shapes of root architecture. The results showed that the normalized mean value of computational root traits from DIRT/2D and DIRT/3D indicated significant discrimination among B73 across environments. We found a strong correlation (R^2> 0.8) between the traits measured in 3D point clouds and manually measured traits. Ear weight and shoot biomass in low N significantly decreased by 45% and 21%, respectively. Low N reduced the maximum root system diameter by 13%, root system diameter by 10%, and root system length by 9%. The 2D and 3D whole root descriptors distinguished three different root architectural shapes of B73 in the same field. Our study assists plant breeders to improve crop productivity and stress tolerance in maize.

Introduction

Ideotype

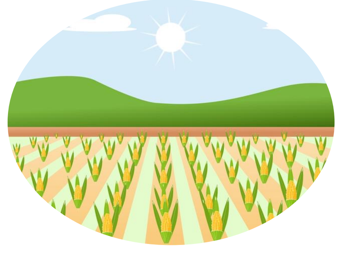


One genotype and one environment

One root architecture

- Sampling for the most common phenotype
- Individual trait was measured locally

Phenotypic spectrum



One genotype and one environment

Multiple root architectures

- Common bean (Xie et al., 2021)
- 2D imaging
- Inability to provide precise information

Our work

To evaluate the phenotypic spectrum of maize root architectures by using manual, DIRT/2D and DIRT/3D phenotyping protocols.

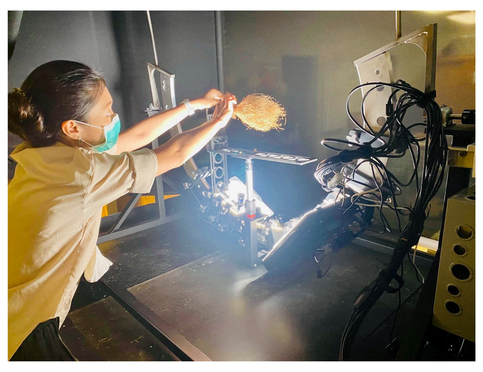
Methods

B73 maize line

Experimental design

- Non-limiting conditions
- High N field
- Low N field

Maize harvesting



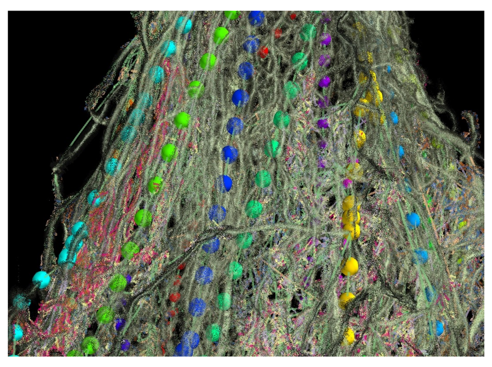
3D scanner

3D reconstruction

Singularity containers

High Performance Computing (HPC)

docker



Trait measurement

Data analysis

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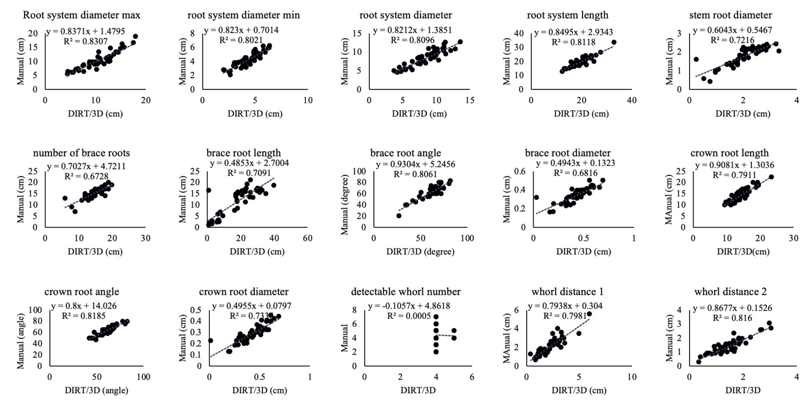
Results

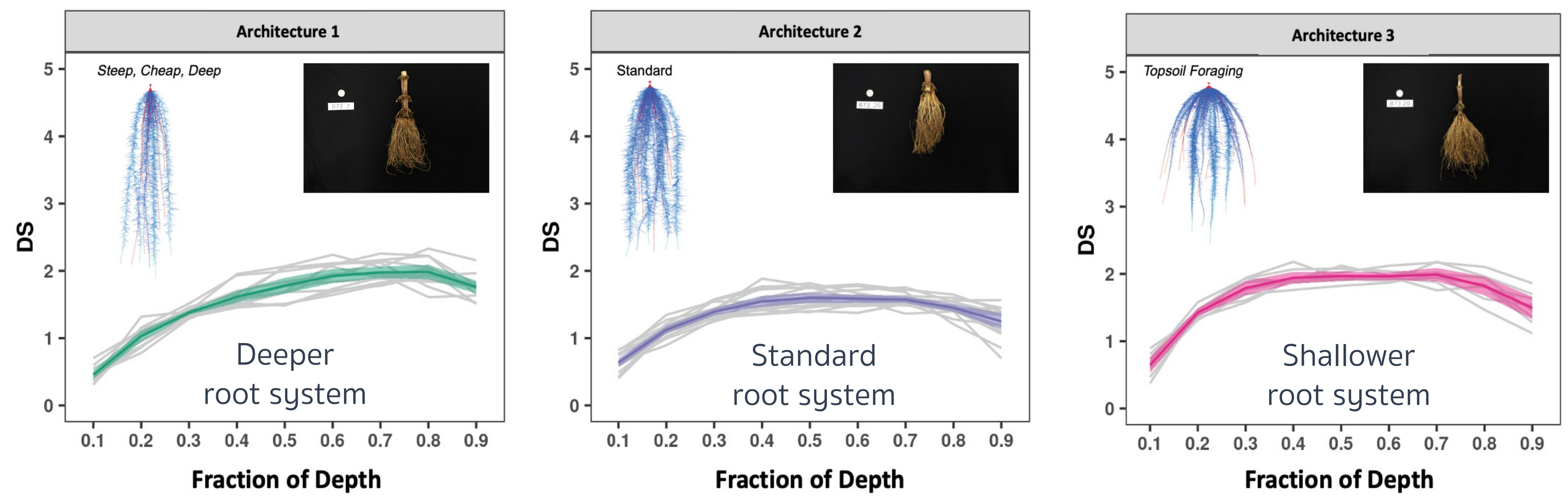
1. Method validation

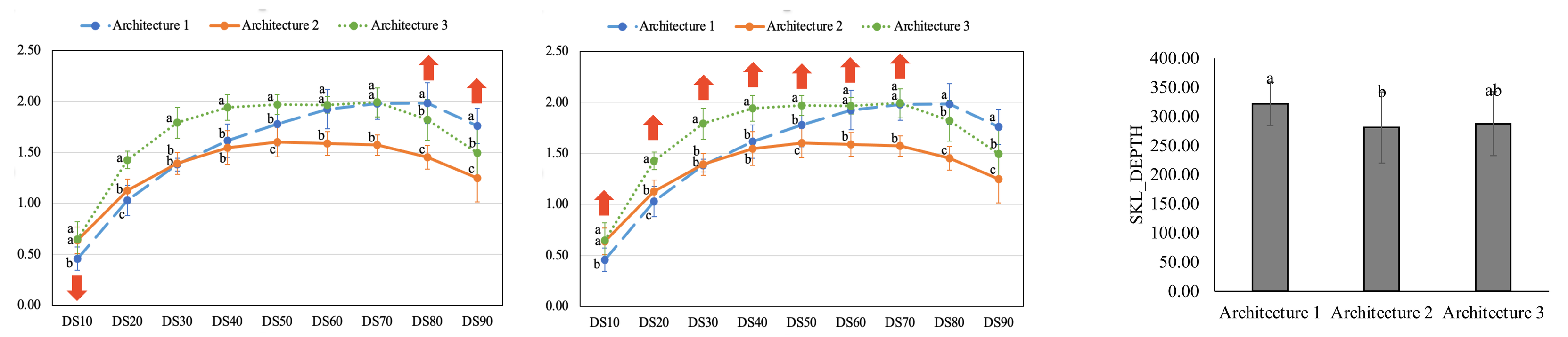
- Strong correlation (R^2 > 0.8) between automatically measured 3D root traits and manually measured traits



2. 2D root architectural shapes

- DS curve could distinguish three different root architecture types of B73 maize grown in the same field.

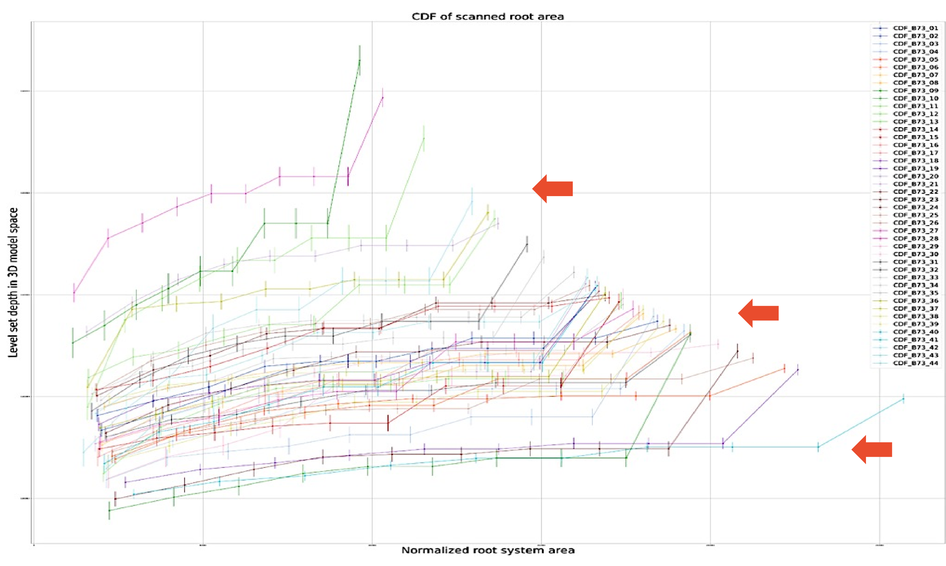


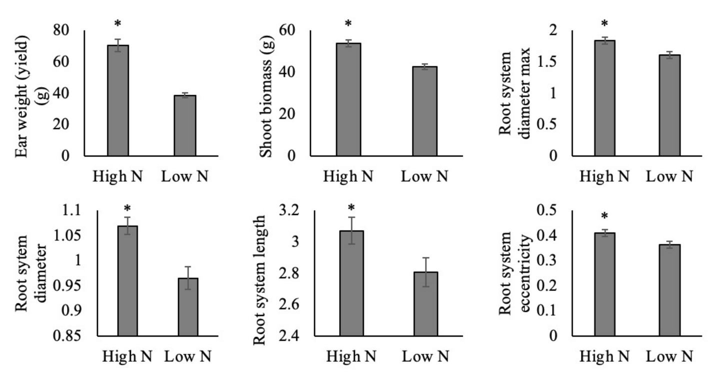


- Root architecture 1 -> Lower rate of width accumulation (DS10) increases until DS80 associates with deeper excavated root systems. Results suggest benefits for water and N uptake (Lynch, 2019)
- Root architecture 3 -> Shallower root system due to fast-changing rate of the root width accumulation at the beginning from DS10 to DS40, then constant rate from DS40 to DS70. Results suggest benefits for P uptake (Lynch, 2019)

3. 3D root architectural shapes

- CDF curve: Accumulation root area over the depth computed from top-down level sets.
- Preliminary results show that the root architectures of B73 maize distinguish visually. However, this first visual observation needs further verification.





4. Low N effects on biomass and root traits measured by DIRT/3D

- Ear weight and shoot biomass in low N significantly decreased by 45%, and 21%, respectively.
- Low N reduced root system diameter max (13%), root system diameter (10%), root system length (9%) and root eccentricity (11%).

Discussion and conclusion

- The modified DIRT/3D method is reliable and showed strong correlation between DIRT/3D and manual measurement.
- DS and CDF graphs could distinguish root architectural shapes of maize.
- 2D and 3D whole root descriptors distinguished three different root architectural shapes of B73 in the same field.
- We want to apply the presented methods to study the phenotypic spectrum of root architectural shapes in maize in high and low N conditions.

Acknowledgements

This project was supported by NSF CAREER Award No. 1845760 to Alexander Bucksch and the Science Achievement Scholarship of Thailand to Jitrana Kengkanna.