Designing crops bottom up: matching rooting systems to sites and seasonal conditions

Daniel Rodriguez[1]

[1] Centre of Crop Sciences, Queensland Alliance for Agriculture and Food Innovation (QAAFI), DigitalAg Building (#8115) Gatton Campus, The University of Queensland

Key words

roots, drought, wheat, sorghum, varietal differences, agronomy, breeding, precision agriculture

GRDC code

Root structure and function traits: Overcoming the root phenotyping bottleneck in cereals UOQ2312-009RTX

Take home message

Root systems are crucial for water and nutrient uptake in crops but have been overlooked in breeding and agronomy for drought adaptation.

A new GRDC-invested project is developing non-destructive root phenotyping tools for more accurate, cost-effective field measurements of root traits.

These tools are designed by a multidisciplinary team from Australia and Germany, including plant breeding and digital agriculture companies.

The project aims to help breeding companies identify drought-tolerant rooting systems and enable precision agriculture providers to offer new services to the grains industry.

Given that grain production in Australia is mainly limited by water availability, it is rather perplexing how little we know about the rooting system, the most critical plant organ to access soil water and nutrients.

However, root traits are hard to measure and the lack of quick, cheap, accurate and functional root phenotyping approaches in the field, has limited the capacity of breeding, agronomy, and precision agriculture to develop valuable traits and services for the grains industry.

We do know that the crop's genetic background, crop management, and the environment interact to alter the architecture of the rooting system. However, rarely have studies on root architecture been able to relate these differences into valuable information such as differences in root function, and implications for yield, or yield stability in the field.

Lack of success can be traced down to the complexity and limited understanding of the relationships between root form (architecture), root function (water and nutrient uptake), and grain yield. A major bottleneck has been that the characterisation of the below ground parts of crops is laborious, expensive, and subject to large errors, as usually only a limited part of the rooting system can be destructively sampled by digging out roots. Another major problem has been that most root studies are done by growing single or multiple plants in pots, root chambers or tubes, which adds important artifacts compared to growing crops in the field. Also, researchers appear stubbornly focused on trying to visualise the root architecture, producing impresive visualisations of the rooting system, while ignoring the weak and highly variable relationship between root form and root function. In addition, the predominant focus of research has been limited to just measuring the mean value of root traits, for example maximum rooting depth of a particular crop or variety, overlooking the fact that the root system is highly responsive to the environment, and that different genotypes show different capacity to adapt to that environment when under stress.

Aiming to alleviate this bottleneck a new GRDC-invested project, being led by the University of Queensland (UQ)-Queensland Alliance for Agriculture and Food Innovation (QAAFI), is delivering root phenotyping tools to enable valuable crop root structure and function traits to be measured non-destructively in the field with greater accuracy, cost-effectiveness, or throughput than current methods.

The project brings together a multidisciplinary team of national and international researchers from QAAFI, UQ, Department of Primary Industries Research and Development (DPIRD), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the Leibniz Institute of Plant Genetics and Crop Plant Research (IPK) in Germany, to work in collaboration with seed companies (Pioneer® Seeds Australia, Pacific Seeds™, Australian Grain Technologies, and LongReach Plant Breeders) and providers of digital and precision agriculture services (Airborn Insight and DataFarming), to deliver actionable solutions to industry and farmers. The project will also build capability for the Australian industry through the training of postgraduate and post-doctorate scientists in the use of new approaches to examining functional crop rooting traits in the field.

What is new?

The project's approach is integrating new functional, high-throughput phenotyping tools with the trait pipeline approach applied in pre-breeding programs and commercial seed companies, where there is simultaneous development of screening methods and evaluation of valuable traits in relevant germplasm. Applications for agronomy and precision agriculture are also explored.

We combine time-lapsed electromagnetic induction (EMI) surveys, drone imagery, crop-ecophysiology principles, and machine learning techniques, to build 2D and 3D representations of root growth and activity in the soil profile.

The methods were originally developed within the GRDC's project 'Optimising Sorghum Agronomy in the Northern Grains Region', and latter applied to map plant available water capacity in growers' fields in another GRDC-invested project.

In principle, an EMI unit is dragged over the soil in between the crop rows (Figure 1), and a data pipeline (Figure 2) is used to derive 3D maps of crop water use in the soil profile.

Figure 1. Applications of UQ-QAAFI's high-throughput functional phenotyping of rooting systems.

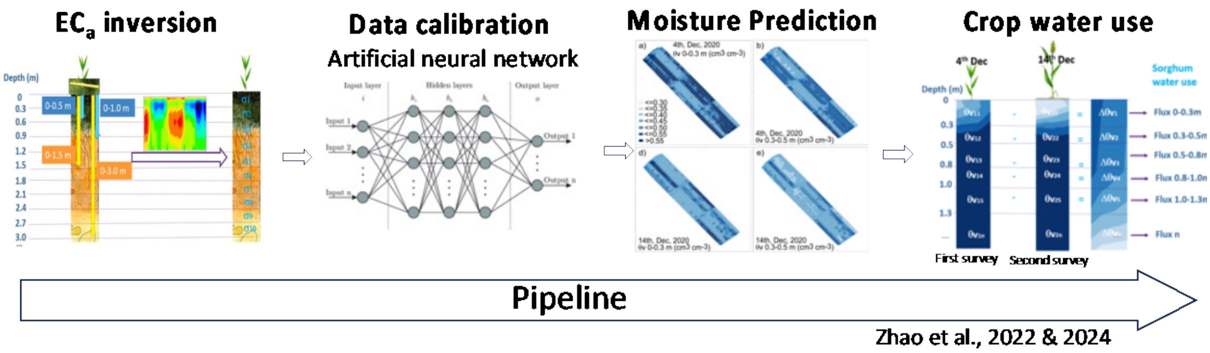

Figure 2. Data pipeline used in the production of 3D maps of crop water use.

The values of crop water use are then used together with drone imagery to derive root traits, such as an 2D index of 'root activity' in the soil profile and the maximum rooting depth across whole fields.

We have shown that the EMI derived root traits are related to important root traits measured in the field through destructive root sampling, such as the root length density, across a wide range of environmental conditions (Figure 3).

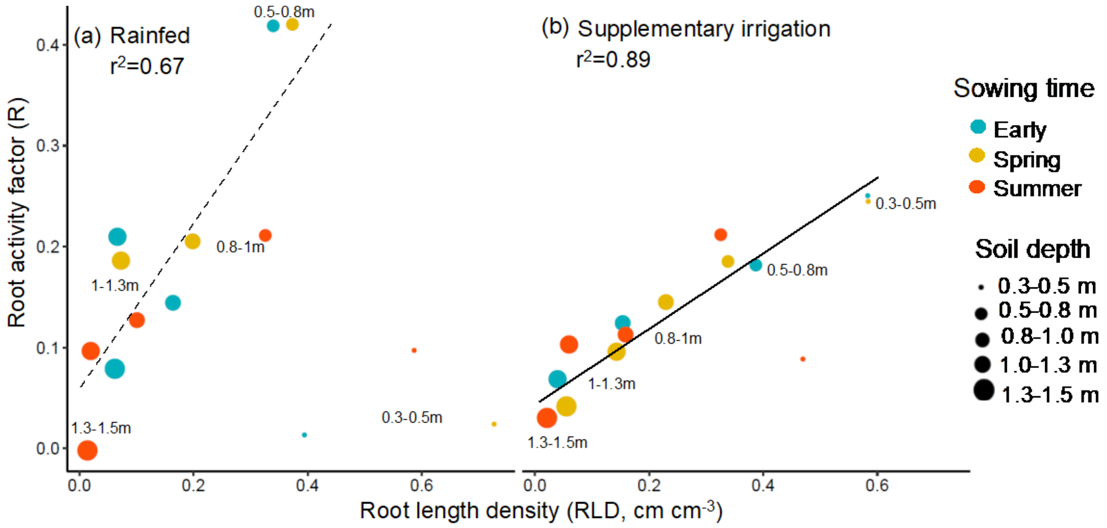

Figure 3. Relationship between the EMI derived root activity factor (y axis) and destructively measured root length density (x axis) in the soil profile, for MR Buster (sorghum) grown under rainfed (a) and supplementary irrigation (b), and three times of sowing (early, spring and summer), in a farmers field near Nangwee Queensland. The size of the dots represents the soil depth layer. Source: Zhao *et al.,* 2024.

Importantly, our results also show that differences in yield between commercial sorghum hybrids, in response to different levels of plant available water (dry / wet conditions), could be explained by differences in their capacity to explore deeper soil layers under dryer conditions (Figure 4). In Figure 4 hybrid A tends to over yield hybrid B in the better (wetter seasons), while hybrid B tends to over yield hybrid yield in drier seasons. Commercial hybrids that tend to behave like hybrid A are Cracka, G33, HGS-114 and MR-Buster, and hybrids that tend to behave like hybrid B include A66 and Agitator.

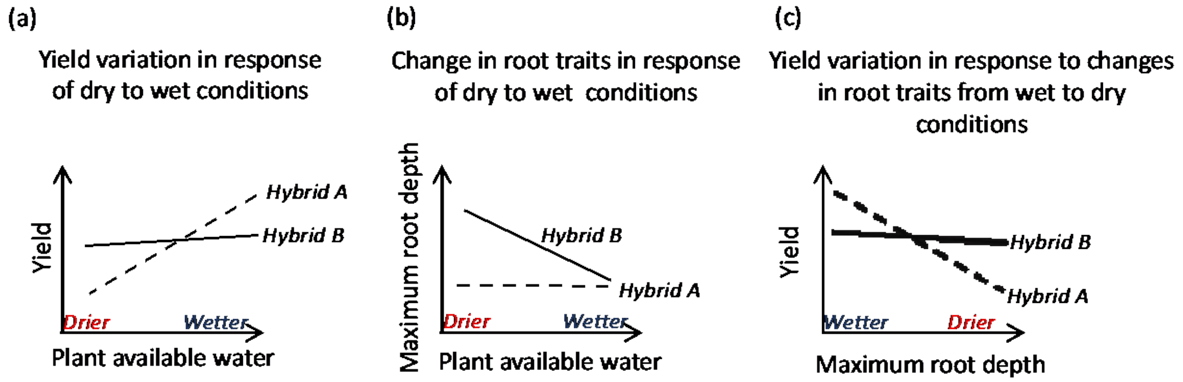

Figure 4. Relationships between the yield (a) and root (b) responses to plant available water, and (c) implications for grain yield on Australian commercial sorghum hybrids. Summary results from two seasons of field trials. Source: D Zhao *et al.,* 2024.

Our approach to high-throughput functional root phenotyping in the field, is quick, cheap, and accurate, and when applied across contrasting growing environments not only allows us to assess the average value of a root trait but also its variability in response to changes in environmental conditions or management practices such as plant density, row configuration, fertilisation, soil amelioration, or irrigation.

This is the first time that a root phenotyping approach in the field allowed us to explain changes in crop yield, yield components and their stability, offering opportunity to overcome the present root phenotyping bottleneck in cereals for breeding and agronomy.

Validation of these new sensing techniques, and the collaboration with root anatomy experts from IPK in Germany, will open opportunities to examine further below-ground crop root traits of interest to boost crop performance.

The project team is working closely with wheat and sorghum pre-breeding programs, breeding companies and providers of digital ag services, providing a clear pathway to market. This ensures that project outputs will be relevant, valuable, and actionable by/to industry, and adoption accelerated.

References

Zhao D, Eyre J, Wilkus E, de Voil P, Broad I and Rodriguez D (2022) 3D characterization of crop water use and the rooting system in field agronomic research. Computers and Electronics in Agriculture, 202. https://doi.org/10.1016/j.compag.2022.107409

Zhao D, de Voil P, Rognoni BG, Wilkus E, Eyre J, Broad I, Rodriguez D (2024) Sowing summer grain crops early in late winter or spring: effects on root growth, water use and yield. Plant Soil https://doi.org/10.1007/s11104-024-06648-0

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. We also thank the significant contribution from Pioneer® Seeds Australia, Pacific Seeds™, AGT, and LongReach Plant Breeders, Airborn Insight, and DataFarming.

Contact details

Prof Daniel Rodriguez
Centre for Crop Sciences
Queensland Alliance for Agriculture and Food Innovation (QAAFI)
DigitalAg Building (#8115) Gatton Campus
The University of Queensland
Email: d.rodriguez@uq.edu.au

Date published

July 2024