PhD Project Advertisement

Project title: The mechanisms and genetics of phosphorus-efficiency in crop plants
Project No: FBS2024-055-Kirk-cr

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Project description:

Phosphorus (P) deficiency is a major constraint to crop production globally due to the limited availability and high cost of P fertilizer resources coupled with low mobility of P in most soils. Certain plant species are well-adapted to growth on low-P soils through a combination of mechanisms internal to the plant allowing more growth for a given amount of P, and external to it, allowing more P uptake for a given concentration in the soil. A promising strategy for more-efficient use of P reserves is to exploit such mechanisms to breed more P-efficient crop varieties. Upland rice – which, unlike lowland, paddy rice, is grown in unflooded conditions – is particularly well adapted to low P soils, and efficient donor genotypes have been identified. Upland rice is a major staple crop, particularly in sub-Saharan Africa where P deficiency is often a principal constraint to yields. In addition, understanding of the mechanisms and genetics of P-efficiency in rice, with its relatively simple genome, could be used to develop P-efficient genotypes of other cereals.

Members of the project team have recently made three advances towards understanding factors that drive P uptake by upland rice. First, we have shown the importance of fine, short, hairy lateral roots, known as S-types, which branch off coarser lateral roots and the main roots (Fig. 1). The S-types massively increase the total root system length, suggesting a particular role in acquisition of P for which a large root surface is important. Second, we have shown with mathematical modelling that S-types play a critical role in P efficiency by increasing the recovery of soil P that has been made more soluble – and hence available for uptake – through root-induced changes in soil chemistry (Fig. 2). Third we have shown that the costs in terms of P invested to construct and maintain S-type laterals are far less than those for other, coarser roots. We estimate that the P costs of constructing S types are paid back by their P uptake within a day of their formation, whereas pay-back times for coarse laterals and main roots are 5 and 25 days, respectively.

The above work focused on the crop establishment and vegetative growth stages. It is possible other processes are involved at later growth stages, for example through symbiosis with mycorrhizal fungi that colonise the roots. As the new mycorrhizal network is established each growing season, mycorrhizal hyphae (the long, branching, thread-like fungal filaments that spread out through the soil) will only provide additional P to the crop once the root system has expanded sufficiently to support them, and their P uptake exceeds the P costs of establishing them.

We have shown genotypic differences in P uptake efficiency exist in rice during this pre-mycorrhizal phase. The aim of this project is to test the hypothesis that genotypic variation in root morphology and root-induced P solubilization are more important for P efficiency than mycorrhizal colonization, particularly during early growth stages. We have the following specific objectives towards this end.

1. To investigate P acquisition processes in contrasting upland rice genotypes over the growing season in controlled-environment experiments in a highly weathered, strongly P-sorbing Oxisol imported to Cranfield from Madagascar in a previous project.
2. To quantify the extent to which mycorrhizas contribute to P uptake in experiments with mutant lines in which the OsPT11 gene, needed to transfer P from mycorrhizal symbionts to the host plant, is knocked out, and using a novel high throughput screening technique for quantifying mycorrhizal colonization of roots based on a

biochemical marker in the above-ground shoots.
3. To parameterise our existing mathematical model of the effects of root morphology, solubilization and mycorrhizas on P uptake under our experimental conditions, and to make sensitivity analyses of the model with which to explore genotypic differences in P efficiency mechanisms.

The project builds on the three recent breakthroughs in understanding of P efficiency in rice by members of the project team, described above. It is therefore at the forefront of research into this topic and will feed into continuing efforts to breed more P-efficient genotypes of rice and other cereals that members of the project team are involved in.

Training opportunities:
This is a great opportunity to work in a project at the cutting edge of bioscience for sustainable food systems and to learn the latest techniques in plant physiology and genetics, soil biogeochemistry, mathematical modelling and marker-aided plant breeding. Training will include interactions and lab visits with Profs Matthias Wissuwa at Bonn and John Hammond at Reading over the course of the project. We are a strongly multi-displinary team and our research spans the range of basic plant and soil sciences through to applied plant breeding. The PhD will learn from and contribute to a full breeding programme for crop P-efficiency.

Cranfield PhD students all receive core, generic training, e.g., in project management, data management, statistics, academic writing and presentation skills. A wide range of MSc modules are available at CU, including Evaluating Sustainability and Economic Appraisal. The student will join a group of over 50 PhD students in the Cranfield Environment and Agrifood Theme, including students from other UKRI-funded doctoral training centres, including CENTA (Central England NERC Training Alliance) and DREAM (Data, Risk and Environmental Analytical Methods), as well as the Food Biosystems DTP. They will have access to a full range of associated training modules.

Student profile:
The project is suitable for students with a BSc degree (minimum upper second class honours) in biology, chemistry, environmental science or a closely related science.

Stipend (Salary):
FoodBioSystems DTP students receive an annual tax free stipend (salary) that is paid in instalments throughout the year. For 2023/24 this is £18,622 and it will increase slightly each year at rate set by UKRI.

Equality Diversity and Inclusion:
The FoodBioSystems DTP is committed to equality, diversity and inclusion (EDI), to building a doctoral researcher(DR) and staff body that reflects the diversity of society, and to encourage applications from under-represented and disadvantaged groups. Our actions to promote diversity and inclusion are detailed on the FoodBioSystems DTP website.

In accordance with UKRI guidelines, our studentships are offered on a part time basis in addition to full time registration. The minimum registration is 50% FT and the studentship end date will be extended to reflect the part-time registration.

References:

- Dinh LT, Ueda Y, Gonzalez D et al. (2023) Novel QTL for Lateral Root Density and Length Improve Phosphorus Uptake in Rice (Oryza sativa L.). Rice 16, 37. https://doi.org/10.1186/s12284-023-00654-z
- Gonzalez D, Postma J, Wissuwa M (2021) Cost-benefit analysis of the upland rice root architecture in relation to phosphate: 3D simulations highlight the importance of S-type lateral roots for reducing the pay-off time. Front Plant Sci 12:641835. https:// doi. org/ 10. 3389/ fpls. 2021. 641835
- Nestler J, Keyes SD, Wissuwa M (2016) Root hair formation in rice (Oryza sativa L.) differs between root types and is altered in artificial growth conditions. J Exp Bot 67:3699–3708.
- Kuppe CW, Kirk GJD, Wissuwa M, Postma JA (2022) Rice increases phosphorus uptake in strongly sorbing soils by intra-root facilitation. Plant Cell Environ 45:884–899. https:// doi. org/ 10. 1111/ pce. 14285
- Wissuwa M, Gonzalez D, Watts-Willliams SJ (2020) The contribution of plant traits and soil microbes to phosphorus uptake from low-phosphorus soil in upland rice varieties. Plant Soil 448:523–537. https:// doi. org/ 10. 1007/s11104- 020- 04453-z.

For up to date information on funding eligibility, studentship rates and part time registration, please visit the FoodBioSystems website.