



Root Phenomics-New Windows to Understand Plant Performance and Increase Crop Productivity

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Roots with ideal characteristics are important for sustaining crop yields, particularly when plants are grown in soils with inadequate water and nutrients [1-4]. Understanding the development of roots and their interaction with the soil environment is vital to manipulate the root traits, and ultimately, the food security [5]. For instance, rice has a significant level of genetic variation in root traits [6-9], that can be harnessed for improving its adaptation to abiotic stresses. However, genetic improvement of root systems through phenotypic selection at the breeding level is impractical due to complexity in phenotyping root traits [3,10,11].

Monoliths, soil cores and minirhizotrons have so far been the methods most commonly used for field root phenotyping, whereas methods relying on aeroponics, hydroponics, moistened paper roll towel, metallic net floating and petri dishes, have been used for the high-throughput screening of root system architecture (RSA) under controlled conditions. These high-throughput methods have been widely used to identify QTLs in several crops. The other medium-throughput innovative methods, namely root basket, have been employed recently and also cloned a major deeper rooting quantitative trait loci (*Dro1*) that determines the RSA in rice [12-14]. This approach maintains the shallow and deep orientation of roots, enabling the sequential screening of ratio of deeper roots. Field validation of *Dro1* introgressed lines of IR64 demonstrated positive relationship between RSA and yield performance under drought stress [14]. This validation will be essential for testing the field application of promising root traits that are identified under controlled conditions. So far, limited literature is available for the analyses of genetic factors contributing to RSA due to the difficulty in observing root distributions and complexity of environmental effects under field conditions. This review paper will highlight the recent advances in root phenomics technologies and their possibility to apply these techniques in crop phenotyping experiments that are relevant for plant performance field conditions.

Although root phenotyping has been a bottleneck for trait-based selection in the past, innovative high-throughput methods have been developed recently, allowing the evaluation of many root traits and phenes that could be important for resistance to abiotic stress. Recent advances in methods to measure root traits suggest that high-throughput simple screening techniques are also becoming available for field studies. Recently, Trachsel et al. [15] developed a shovelomics strategy of screening RSA traits in the field with a high-throughput phenotyping of Maize. With this strategy, ten different architectural traits of the root crown of field grown maize plants were visually scored [15]. Also, there is a great potential to apply the same strategy to rice, and with increased efficiency by using recent analytical methods, such as morphometric or fractal analysis. Taking imaging techniques from the medical field, phenomics offers to crop physiologists new choices into the inner workings of crop plants. Over the past decade or so, non-destructive methodologies, including ultrasound, magnetic resonance imaging and X-rays have been used in soil systems, in an attempt to confine the inner space of soil and its contents in three dimensions [16-18]. Recent advances in Computed Tomography (CT) have led

to improvements in scan resolution, quality, acquisition time and sample size. Of all possible non-destructive techniques, CT has been renowned as the one that is able to deal effectively with the complex geophysical and geochemical complexities of soil across wide range of environments [19]. Also, CT technology serves as a stepping stone for a better understanding of the role of plants in the critical zone at the soil-atmosphere interface.

Recently, investigation observed a high correlation between micro-CT-observed wheat roots and roots observed by standard methodology. The CT technique is speedy, safe and sound to detect roots at quite high spatial resolutions [20]. The drawback of the CT methodology lies not in the scanning technique, but in the software available to digitally segment roots from soil and air. However, this will be improved significantly as automated segmentation algorithms are developed [20]. This can be achieved through the strong collaboration between software engineers and crop physiologists. The combination of very fast scans and programmed segmentation will allow CT methodology to perform its potential as a high-throughput technique for the examination of roots in soils. A novel 3D imaging and RootReader3D software platform was developed for high-throughput phenotyping of root traits in rice [21]. This sophisticated platform provides the capability to measure root traits with a high degree of spatial and temporal resolution, and will facilitate novel investigations into the development of entire root systems or selected components of root systems.

More recently, root-tracking algorithms were developed to segment roots from their surroundings by using features of roots, such as shape and continuous growth [5,22,23]. RooTrak can successfully, with minimal user intervention, extract a range of RSA from the surrounding soil and promises to facilitate future root phenotyping efforts [5]. As said above, new technologies can be employed to dissect the phenotypes for genetic mapping and in physiological studies for trait validation in crop breeding programmes.

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