Dynamics of root–soil systems

A. Glyn Bengough, Paul D. Hallett, Blair M. McKenzie, Tracy A. Valentine & Nathalie Wuyts

Plant roots experience a range of stresses in the soil environment, and also have capacity to modify the physical behaviour of soil. As agricultural practice becomes increasingly mechanised and more concern is placed on the ecosystem services provided by soils, understanding these complex root–soil interactions is essential to developing sustainable cropping systems. In combination with climatic factors, such as the frequency and intensity of rain, soil mechanical and hydraulic properties control the size, nature and extent of root systems. These constraints can affect crop yield and quality. Given the uncertainties associated with global climate change, it is crucial that we both understand and manage the soil–plant system to deliver stable crop yields whilst enhancing biodiversity in agroecosystems, and minimising environmental pollution by agrochemical leaching. We are therefore studying root responses to soil physical conditions, from the molecular level to field scale, to understand how roots respond to changes in soil strength, structure and water potential.

The extent of a root system controls the volume of soil the plant can exploit for water and nutrients. Root length densities (length of root per volume of soil) are often large in fertile agricultural topsoils. However, in subsoils and poorly structured topsoils, roots can be confined largely to pre-existing channels and biopores, decreasing the efficiency of water and nutrient extraction. The main physical factors limiting root growth are mechanical impedance (soil that is too hard), drought (insufficient available water), and waterlogging (insufficient air-filled pore-space). By quantifying how these stresses change with time and location in the soil profile, we can understand the stresses limiting root growth. Results to date indicate that soil strength is often the major factor limiting root growth. We are evaluating how soil strength may be controlled by soil management and its subsequent effects on plants.

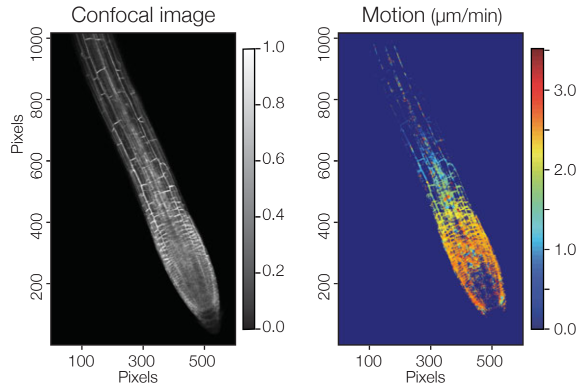

Figure 1 We are developing image analysis techniques to study physiological mechanisms underlying root responses to stress. This figure shows the cellular motion caused by cell expansion in growing *Arabidopsis* roots (BBSRC funded).

We are particularly interested in whether certain plant genotypes perform better in problem soils, because we have evidence of significant genotypic variation in root systems of both model plant and crop species. As rainfall frequencies and intensities change, plant roots may be faced with an increasingly hostile soil environment. Working in collaboration with BioSS and the Macaulay Institute we aim to understand how we can best evalu-

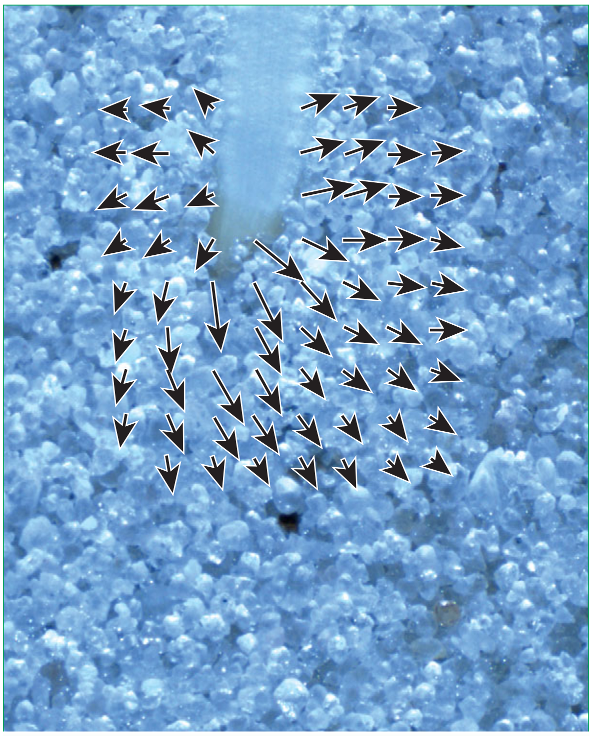

Figure 2 Deformation patterns around root tips growing in sand reveal the mechanics of root penetration.

Quantifying root systems grown in soil columns reveals interactions between root architecture and root function.

ate soil physical properties at a national scale, control them at a field scale and, alongside plant geneticists at SCRI, understand the potential to exploit variation in root system traits for efficient capture of water and nutrients.

The most detailed work involves developing techniques to study the dynamics of cell expansion in relation to external stresses. For example, Fig. 1 shows results from a new image analysis method developed in collaboration with the department of Applied Computing at the University of Dundee (Tim Roberts and Stephen McKenna) to determine the rates of cell expansion in roots of the model plant species *Arabidopsis*. We have recently applied a related technique to study deformations of the soil around growing roots (Fig. 2), in collaboration with the Agricultural University of Norway (Ane Vollsness). Developing these methods and applying them in novel ways elucidates the mechanisms controlling root penetration of soils, whilst scaling up to the glasshouse and the field allows consideration of whole root system responses under real conditions.