Keynote presentation

K-1077 The biophysics of the soil-root interface

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Most of the functionally important volume of soil is reprocessed in the region immediately adjacent to a root (the rhizosphere) during crucial periods that impact on the sustainability of biophysical processes, and plant development over time. The rhizosphere, although small in volume, has a large and distinctive effect on all plant development and is the home to the largest populations of micro-organisms in soil (Young 1998; Watt et al., 1994; Whalley et al., 2005). Whilst is established that the rhizosphere is of prime importance in determining the function of soil primarily with respect to plant function, it is relatively poorly characterized.

Experimental measurement of in-situ characteristics/processes of the rhizosphere, at adequate (<1 μm) resolution, is seen as one of the main reasons for our limited understanding of most rhizosphere processes (Bengough, 2004; Darrah et al. 2005). Currently, the soil matrix is viewed as a homogeneous entity and fine scale details like root/soil interfacial changes and pore geometries are neglected or subject to extreme spatial averaging. We have limited knowledge of any of these details. The partitioning of resource flows to the root is determined by the interplay between pore scale structure and moisture, with increasing moisture content reducing the availability of oxygen while increasing the availability of water. Characteristics such as pore geometry and connectivity, which define hydraulic and gaseous pathways in soil, are markedly different in 3D as opposed to 2D.

This presentation will focus on the soil system as a 3D heterogeneous habitat through which roots develop. It will discuss the soil-microbe-root system as a self-organised system (Young & Crawford, 2004). Emphasis will be placed on the role of root-microbe interactions mediating pore geometry and function and the role of the pore geometry mediating subsequent biotic activity. Examples will be provided in relation to the impact of exudates on moisture and the role of the inner space of soil in mediating permeability and the dispersal of fungi and bacteria.

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▶ *Oral presentations*

O-780 Generating the rhizosphere: deformation of soil around roots is related to mechanical impedance and root cap properties

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Roots deform and compress newly penetrated soil that will form the rhizosphere, modifying its physical properties. The resistance to soil deformation constitutes a mechanical impedance to root growth, and is often the most important physical factor limiting root growth in drying soil (Bengough et al. 2006). We report novel measurements of soil displacements in the forming rhizosphere, where particles are displaced ahead and to the sides of the growing root tip. We measured particle displacements for maize roots growing in fine sand (water content 6g/100g), using a particle image velocimetry technique developed in geotechnical engineering (White et al. 2003). Deformation measurements were made successfully with high spatial and temporal resolution around root tips of maize (KYS, and the Agt1 mutant – both intact and decapped). The primary root of Agt1 has a root cap that does not produce mucilage, and that is removed easily, due to a weak root cap junction. Deformation patterns indicated that greater displacement of sand occurred ahead of the root tip for decapped mutants, probably due to a greater component of frictional resistance to growth. Measurements of deformation patterns around root tips were used to estimate rhizosphere densities – a property important in physical, chemical and biological interactions in the rhizosphere. Results will be discussed also in the context of the genotypic variation in maize border cell production, and the pressures required for roots to penetrate soil.

Acknowledgements: Thanks to D White for access to the Cambridge University PIV code.

Bengough AG, Bransby MF, Hans J, McKenna SJ, Roberts TJ, Valentine TA. 2006. Root responses to soil physical conditions; growth dynamics from field to cell. Journal of Experimental Botany 57, 437-447.

White DJ, Take WA, Bolton MD. 2003. Soil deformation measurement using particle image velocimetry (PIV) and photogrammetry. Geotechnique 53, 619-631.

O-1052 Architectural responses of plant roots to high and low density interfaces in soil: visualisations in 4-dimensions

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X-ray- imaging with computed tomography was used to monitor, non-invasively, the development of root systems in response to physical features in soil that might encourage or restrict growth. Two scanning systems with different resolution and sample size capabilities were used, a medical X-ray (Aquilion, Toshiba, Japan) and micro-CT (Skyscan, Belgium). Intact cores of soil (15cm diameter and 50cm depth) enclosed in PVC cylinders were collected from a farming region in South Australia. The texture contrast soil comprised 20-30cm of sandy top soil and a dense sodic clay subsoil. The cores were taken from sites where soil had not been ameliorated and from sites where soil had been 'deep ripped' to 50 cm. Cores underwent medical X-ray scanning and 3D images of the porosity were rendered using computer tomography. A range of plants including annual and perennial species (oilseed rape, saltbush and lucerne) were grown in individual cores. At intervals during plant development cores were scanned in a medical X-ray CT scanner. Intact small sub-samples (2cm x 2cm x 2cm) were also taken from selected cores, at the interface of the sand-clay layers, for micro-CT scanning. 3D images were rendered with image analysis software (Amira, Template Graphics Software, USA) and analysed for root and/or pore length, surface area, tortuosity and volume using integrated purpose-written skeletonization algorithms. Destructive sampling was also carried out on some of the cores used for 3D analysis and involved root washing and 2D scanning to measure the total length and volume of all roots.

X-ray CT revealed the architecture and morphology of parts of the root system (> 1mm diamter) in situ and tracked response to soil macrostructures such as layers of organic matter in the sand, compacted layers in the sand, the sodic clay domes at the interface with the sand, old root channels, calcium deposits, stones, and areas of soil that were naturally more loose. Root penetration was generally much slower in cores from the non-ripped sites than in cores from the ripped sites, indicating a restriction to growth even in the sand. Superimposition of root and non-ripped soil images showed that the roots grew preferentially in looser soil matrix, organic deposits and old root channels. Micro-CT enabled roots and pores >0.1mm to be visualised and detailed analysis of interactions between roots and soil micro-structure to be carried out.

O-495 Plants may alter competition by modifying nutrient bioavailability in rhizosphere: a modelling approach

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Plants can modify nutrient availability through the release of various chemicals in rhizosphere. This change in nutrient availability induced by roots, i.e. bioavailability, has been shown to improve nutrient uptake by individual plant species that release such compounds. However, can this bioavailability alter plant competition for nutrients? If so, under what conditions ? To address these questions, we have developed a model of nutrient competition between plant species based on a mechanistic description of nutrient diffusion in the soil and plant uptake. The model also accounts for root exudates, that diffuse away from the roots and increase the availability of nutrients for which several plant species compete. The model was parameterized using data from measurements of the effects of root exudation of citrate on phosphorus availability. We then performed a sensitivity analysis for several key parameters to test the generality of effects of bioavailability on competition for nutrients.

Our simulations suggest that: 1) Nutrient uptake by root systems depends on the number of roots when both nutrients and root exudates diffuse little, because individual roots are nearly independent in terms of nutrient supply. In this case, bioavailability profits only species with root exudates. 2) Competition for nutrients depends on the spatial arrangement of roots when nutrients diffuse little, but exudates diffuse widely. 3) Competition for nutrients depends on the nutrient uptake capacity of roots when both nutrients and exudates diffuse widely. In this case, bioavailability profits species with and without root exudates. Our work suggests the mechanisms controlling competition for bioavailable nutrients are diverse and strongly depend on a suite of soil, nutrient and plant characteristics that are not accounted for in previous theories and models of plant competition for nutrients.

O-562 Effects of soil acidity on rhizosphere development in cereals

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Root growth can be affected adversely by soil acidity when concentrations of monomeric aluminium (Al^{3+}) are elevated to toxic levels. The impact of Al and soil acidity on rhizosphere development in wheat and barley was investigated in an acid Oxisol (red Ferrosol) soil to which lime ($CaCO_3$) was applied at 5 rates to modify soil pH and Al concentrations (pH $CaCl_2$; 4.22 to 5.35 and Al; 51 to 0.4 % base saturation, respectively) and soil from an adjacent site which was naturally more acid (pH 4.19, 59% Al). The cereal lines were selected on the basis of differences in rate of root growth, Al-tolerance and root hair morphology. Plants were sown as pre-germinated seeds and root morphology was assessed after 7 days growth.

Total root length of the lines varied considerably and was reduced significantly in soil with high Al. The length of fine roots (0.04 to 0.36 mm diameter) was reduced to a greater extent at high Al levels (i.e., above 31% Al base saturation) than that of coarse roots (0.36 to 0.90 mm) and this was most evident for Al-sensitive lines. Both the initiation (number) and elongation of lateral roots were affected by Al. In contrast, the length of root hairs was reduced similarly in all lines at each Al concentration, with greatest reduction (62 to 71%) occurring at the highest Al level. Root hair density was similarly reduced in all lines with increasing Al (41 to 62% reduction at the highest level of Al). The amount of soil retained on roots as a rhizosheath was also reduced as the Al concentration increased (85-93% reduction in rhizosheath volume at the highest Al level), and this was hypothesized to be associated with the reductions in the length and density of root hairs. The importance of root hairs for maintaining a rhizosheath was highlighted by the complete absence of a rhizosheath on a root-hair deficient mutant of barley (Gahoonia et al., 2001).

These results indicate that morphological characteristics of roots are affected differentially by lime application to acid soil, and that soil acidity and genotype both influence development of the rhizosphere, as demonstrated by their impacts on root morphology and the rhizosheath. This potentially has important implications for nutrient acquisition and the water relations of cereal plants growing in acidic soils with high concentration of Al.

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O-505

Sand-binding roots down-under: formation and functioning

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Root adaptations for acquiring soil nutrients and water have evolved in many plants surviving on intensely weathered soils of south-western Australia. Native rushes (*Restionaceae*) form a prominent but inconspicuous component of the 'grass-like' flora, accounting for more than half the plant biomass in some landscapes. Worldwide there are approx. 480 rush species (ca. 330 in Africa, 150 in Australia, 4 in New Zealand and 1 species in South America). Rush species are common in the understorey in most areas of temperate Australia, but most species occur in south-western Australia (ca. 120) (Meney and Pate, 1999). In rushes, a prominent group in this species-rich flora, "sand-binding" roots have evolved, presumably as an adaptation, to sustain water and nutrient acquisition. The most obvious feature of sandbinding roots is the cylindrical sand sheaths of densely-packed sand particles encasing and tightly adhering to the axis of the root. The sand particles are bound by persistent, often lignified root hairs, and secretions (mucilages etc.) from which are presumed to be responsible for cementing the particles firmly to the root surface. Our project aims to integrate formation, structure and functioning of these root structures. It firstly examines the natural history of the root systems, and then, using an experimental approach with split-root techniques and quantitative cryo-scanning electron microscopy, links their development, structure and function to environmental and developmental signals.

Rushes grow almost exclusively in extremely nutrient-impoverished environments that are characterised by seasonal extremes of drought, flooding and recurrent fire. The root systems of rushes and many other Australian monocots are usually strongly dimorphic which presumably embodies adaptations to low availability of both soil moisture and nutrients. We know that some native dicots (e.g., *Banksia prionotes*) primarily access water by deep 'sinker' roots, whereas acquisition of nutrients, which are predominantly near the soil surface, occurs by seasonally produced shallow 'proteoid' root clusters. What we know about the functioning of Australian rushes (and related species) is very rudimentary, and largely inferred from studies of 'woody' dicot species. The *Restionaceae* offer a unique opportunity to examine the dynamic mode of action of dimorphic roots that evolved to exploit limiting resources in severely nutrient-impoverished, semi-arid ecosystems.

Poster presentations

P-812 Electrical resistivity tomography imaging: a way for assessing water uptake heterogeneity at the field scale

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A better management of irrigation water requires a better understanding of the water uptake process from the single root to the rooted field scales. Imaging of the heterogeneity of the uptake process or evaluation of the active zones of uptake with time could give a better understanding of the functioning of the root systems in situ, in relation with resources availability.

To this aim, we conducted an experimental field study with a maize crop and three different levels of irrigation (well irrigated, moderately irrigated and poorly irrigated). The soil water was monitored with classical devices for water measurements (neutron probe, tensiometers), giving pointwise measurements with depth. In order to get 2D variations of soil water content along horizontal transects in the field, we used an Electrical Resistivity Tomography technique (ERT), which enables the imaging of the electrical resistivity of the soil. Soil electrical resistivity is directly influenced by soil water content, and when measurements are repeated with time along the same transect the difference in time between resistivity values are the reflect of the variation in water content and help to localize zones of active uptake.

Electrical measurements were done with 32 electrodes at the soil surface, 30 cm apart, for a total transect length of 9 m with a Wenner alpha configuration.

The results of the three months monitoring show that variations of water content with time, as measured with neutron probe, denote an increasing depth of water extraction zone from the well irrigated treatment to the poorly irrigated treatment. This global pattern of extraction with depth is also observed with ERT imaging, but the time variation of electrical resistivity images reveal high spatial variations in the uptake pattern: variation between the row and inter row, but more surprisingly high variations at depth too, where patches of high variation are found. This heterogeneity of uptake increases from the well to poorly irrigated treatment.

P-704 The role of microbial diversity in developing soil structure

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Soil still remains one of the most diverse, complex and uncharacterized ecosystems in the environment. Soil microbial activity plays an important role in ecosystem level processes, such as carbon and nitrogen cycling, organic matter decomposition and nutrient distribution, in addition to creating and maintaining soil structure. A crucial question yet to be resolved, is how microbiologically diverse does a soil need to be in order to develop and maintain its physical structure and ultimately, soil quality and function? Whilst there is evidence of species redundancy for functions such as decomposition, this may not be true for key physical processes that influence soil aggregation and hence regulate soil structure. Since it is widely acknowledged that anthropogenic disturbances and potentially climate change will enhance reductions in biodiversity, we have focused on the implications of such localised extinctions on soil stability (an important ecosystem function). Using macrocosms of soil inoculated with microbial communities of different complexity, we investigated the effect changes in microbial diversity had on the development and stability of aggregates, pore size distribution and pore connectivity in a sandy loam soil. Three different treatments containing (1) bare soil, (2) soil and *Plantago lanceolata* and (3) soil with *P. lanceolata* and arbuscular mycorrhizal fungi (AMF) were inoculated to two differing biodiversity levels. Microbial diversity and relative abundance was quantified by a modification of Terminal Restriction Fragment Length Polymorphism analysis (T-RFLP) and functional richness measured using Biolog GN2 microtitre plates. These data and those relating to changes in the soil porous architecture at different scales (μm–cm) in both 2-D and 3-D using X-ray Computed Tomography (CT) will be presented.

P-641 Efffects of different sod cultivation system on soil physiochemical properties and microbial activities of Citrus orchard in dark brown volcanic ash soil

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This study was conducted to investigate effects of different sod cultivation system on soil physiochemical properties and microbial activities in dark brown volcanic ash soil, which cultivated satsuma mandarin (*Citrus unshiu*. marc) from 1997 to 2000. Soil samples were taken in 4 experimental plots such as Clean cultivation system (C.C.S.), Natural sod cultivation system (N.S.C.S.), Kentucky blue grass sod cultivation system (K.B.G.), Natural sod cultivation system with cedar woodchip mulching (M+N.S.C.S.). These plots had been managed the same management practices for 4 years. Soil hardness was low at 10mm in M+N.S.C.S.. Water stable aggregate (>1.0 mm) ranged from 76.6% to 85.2% in sod cultivation system and it were significantly higher than in C.C.S. (59.6%). Porosity was slightly high in sod cultivation system; 63.0 (C.C.S.), 66.3 (N.S.C.S.), 64.4 (K.B.G.), 64.9% (M+N.S.C.S.). The loss of surface soil in M+N.S.C.S. (1.2 t 10 a^{-1}) were at 4.5 times lower than that in C.C.S. (5.5 t 10 a^{-1}). The contents of soil organic matter and available phosphorus increased in sod cultivation system. The contents of exchangeable K, Ca, and Mg decreased in sod cultivation system. Degree of base saturation increased annually in all experimental plots and it was significantly high in M+N.S.C.S. (71.2%). Soil NO_3-N content was slightly higher in sod cultivation system than that in C.C.S. The amount of leaching of NO_3-N and PO_4 in ground water were high in C.C.S., which were 3.05ppm, 1.15ppm, respectively.

The activity of soil acidic-phosphatase was high in sod cultivation system; 241.1 (C.C.S.), 293.5 (N.S.C.S.), 387.1 (K.B.G.), 301.0 μφPNP g^{-1} h^{-1} (M+N.S.C.S.). The amount of Biomass C in K.B.G. (525.4) was about twice higher than that in C.C.S. (261.2 mg kg^{-1}).

P-882 Rooting density and vertical water uptake profiles - what else matters?

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The object of this study is to investigate the impact of plant root architecture on the water uptake characteristics of a root system using a numerical simulation model. Many soil-vegetation-atmosphere transfer (SVAT) models rely on a functional form of rooting density distribution in order to calculate vertical water uptake profiles. However, for a particular plant root system, the Hydraulic Tree Model of Doussan et. al. (1998) showed that not only the rooting density affects the uptake profiles but also root architecture. We extend this idea to extract general properties of root architecture that influence the water uptake profile of a root system.

We use a model scheme based on OutTree, a pointer based data structure reflecting the root system. The root system is constructed of root segments which are represented by circuits of axial and radial resistances. We compare a number of different approaches for describing root systems. Since it is known that systems generating optimal flow paths (like rivers or blood circulation) lead to tree-like structures exhibiting fractal properties, we start by investigating fractal architectures, and compare to simple rule based models for root branching, as well as density distributions.

Using many realizations, we identify robust parameters that best describe the hydraulic properties of a root network (and in particular result in similar vertical water uptake profile). The long term goal of this research is to define new categories of root systems which can be used besides rooting density for water uptake parameterization in SVAT schemes.

P-1070 The influence of spatial heterogeneous root temperatures on plant structure and on nutrient uptake

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It is known that soil temperature influences a wide range of abiotic and biotic processes which take place in plant-soil systems. Due to the fact that in nature soil temperature varies in time and space difficulties arise in determining reactions forced by soil temperature consist. Research on soil respectively root temperature effects on plants is usually done in highly artificial systems (mostly hydroponics) at uniform temperatures for the entire root system or in natural soils without precisely controlling temperature or any other environmental factor. Because it is difficult to distinguish exactly between the effects of water, nutrients and temperature in a natural system, and to establish stable spatial root temperature differences in systems as close as possible to nature in the lab, research with vertical soil temperature differences is scarce.

Therefore, in a “nature like” system the response of plants to spatially heterogeneous root temperature was studied while all other abiotic factors were kept constant. To reach that aim, structural and functional parameters of 30 days old barley plants (*Hordeum vulgare* cv. Barke) were studied in custom-made setups, which allowed to establish stable temperature conditions in the root zone. Plant biomass, the structure of the root systems as well as nutrient uptake were studied for uniform root zone temperatures (RT) of 10, 15 and 20°C and in a vertical root temperature gradient (RTG), top to bottom of 20-10°C. The root architecture was of special interest and was examined in four different root depths (0-5, 5-10, 10-15 and 15-20cm). Stable isotopes (^{25}Mg, ^{15}N) were used as tracers to get information about the dynamics of nutrient uptake at different temperatures.

Analysis showed that the total biomass increases with increasing uniform root temperature. However in a RTG even more biomass was produced, but the root/shoot ratio was constant at all measuring temperatures. Compared to RT not only root length allocation with rooting depth was affected by RTG but also the root diameter composition. C and N concentrations in the entire plant were equal within each part of the plants grown under RT. In comparison, C and N concentrations in roots of plants grown under RTG were lower, whereas shoot values did not differ. The results of the nutrient uptake experiments using stable isotope tracer for N and Mg indicated an influence of the root system structure on uptake.

P-1009 Resistance of *Pseudomonas putida* kt2440 to natural desiccation.

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Pseudomonas putida KT2440 is a saprophytic bacterium extensively characterized and its genome has been sequenced (2). This bacterium uses diverse aromatic compounds as carbon sources (4). Since *P. putida* is a proficient plant colonizer it could be used as agent for rhizoremediation of xenobiotics. A potential impediment for its exploitation is the extremely susceptibility to desiccation under freeze-drying conditions, depending on the amount of C17: cyclopropane present in the membrane (1). We explored the resistance of the strain to desiccation under natural conditions (air, soil and interaction with plants). The bacterial resistance to desiccation was increased when the strain was associated to maize roots. Plants exudate a huge diversity of substances (3) (amino acids, organic acids, sugars, lipids), which could protect bacteria during the desiccation process. We explored the ability of different substances present in exudates for protecting *P. putida* KT2440 from desiccation under controlled environmental conditions (30°C and 30% of environment humidity). Bacteria survival was diminished as water decreased, both with the tested substances or without them. When a protective substance was not used the bacterium survival diminished drastically (Bacterial Survival Rate under air desiccation (BSRa)=0 at 12 days post desiccation (dpd)). Contrastingly, in the presence of some substances such as glucose, sucrose, and poly-alcohols, the survival was increased enormously (for glucose, BSRa=95 at 18 dpd). The explored amino acids and organic acids did not protect *P. putida* KT2440 from desiccation. Rhizosphere could be essential for the survival of the bacterium during desiccation; nevertheless, only some exudates of the plant are keys for bacteria survival in dry environments. The knowledge of the mechanisms used by *P. putida* KT2440 to persist in dry environments, are imperative for a successful rhizoremediation of contaminated environments, particularly in arid soils.

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P-1131 Frost hardiness of ectomycorrhizal fungi in pure culture

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Although soil temperatures tend to be less extreme than air temperatures, soil frost is common in most of the boreal zone. Aboveground parts of northern trees are often adapted to tolerate temperatures down to -80°C, but in some studies, fine roots have not tolerated lower temperatures than - 5°C. On the other hand, in the field, massive diebacks of mycorrhizas have not been recorded in winter even near the soil surface. We hypothesised that 1) mycorrhizal fungi tolerate below-zero temperatures, and that 2) hydrophobic species are more tolerant than hydrophilic ones, due to the relation between the occurrence of free water and the initiation of ice crystallisation.

Pure cultures of *Laccaria laccata*, *Hebeloma* sp. and *Suillus luteus* and *Suillus variegatus* were grown in liquid medium at room temperature (23°C) for 5 weeks. Subsequently, intact pieces of mycelium were rinsed with deionised water, drained, and placed in test tubes. Different groups of samples were subjected to different temperatures between +5°C and -48°C for 4 h, with a cooling and warming rate 5°C h^{-1}. Relative electrolyte leakage (REL) was used for viability assessment. For an estimation of the lethal temperature for 50% of the samples (LT50), the REL data were fitted to a sigmoid function. In a second experiment, the survival of samples of the same isolates was assessed by aseptically transferring them to Hagem agar plates after exposure, and recording their growth.

The estimated LT50 by REL was between - 8.5 and -13.5°C for the three fungal species. However, all isolates resumed growth after exposure to -12°C, hence some of the damage indicated by REL appears to have been transient. No major difference was observed between the hydrophobic and hydrophilic species.

The fungi grown at room temperature tolerated lower temperatures than expected. Possible mechanisms for the hardiness of these fungi include tolerance to intercellular freezing, and cell wall properties which physically prevent the initiation of ice nucleation. The following step is to study the frost hardiness of different mycorrhizas. These studies can yield insights into the reasons for the distribution of different mycorrhizas in different climatic zones, and into the changes that global warming may cause in the fitness of plants, fungi, and their symbioses.