New methods for examining the effects of matric potential and root-soil contact on crop root growth and function

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ABSTRACT

This paper describes the effects of plant species, growth medium and matric potential on root elongation. Maize and lupin were grown in vermiculite and soil for 96 h at matric potentials ranging from -0.03 MPa to -1.6 MPa. Root elongation decreased with decreasing matric potential. Plants showed sensitivity to the growing medium. Root elongation of maize was greater in soil than in vermiculite at matric potentials greater than -1.6 MPa. X-ray computed tomography was used to investigate the root-particle contact of lupin and maize in vermiculite and soil. Greater root-particle contact was found in soil than in vermiculite, which might be correlated with a greater root elongation rate in soil.
KEYWORDS: X-ray computed tomography, 3-D visualization, root growth, root-soil contact, matric potential

1. INTRODUCTION

Root growth decreases as soil dries due to a combination of mechanical impedance and water stress. The reduction of root growth caused by water stress is often not as much as the reduction in shoot growth (Davies and Bacon, 2003). Sharp et al. (1988) investigated the primary root growth of *Zea mays* at different water potentials in vermiculite to avoid the increase in strength that occurs as soil dries. At water potentials drier than -1.5 MPa the primary root elongated slowly, while shoot growth was completely inhibited. Root contact with the soil is essential for water and nutrient adsorption by plants. Root-soil contact is influenced by soil and root properties, such as particle size, degree of soil compaction, root diameter and relative hydration (Tinker 1976, Nye, 1994). In water-saturated and heavily compacted soils, roots can suffer from hypoxia (Veen et al., 1992). Conversely, incomplete root-soil contact due to soil structure or root shrinkage can decrease the uptake of water and nutrients (Veen et al., 1992). This paper deals with the effects of growing medium and matric potential on root growth and the investigation of root-soil contact using X-ray computed tomography. The aim of the study was to investigate the interacting effects of matric potential and root soil contact on root growth of two different plant species (maize and lupin) with different root architectures. A greater root-particle contact in soil than in vermiculite will provide better growth conditions in the range of plant available water.

2. METHODS

2.1. Root elongation and soil matric potential

The root elongation of *Zea mays* and *Lupinus angustifolius* in vermiculite and soil at different matric potentials was investigated using an experimental approach described by Sharp et al.

(1988). *Zea mays* and *Lupinus angustifolius* seeds were germinated for three days and then moved into a bio-assay dish filled with either soil (sieved to 2 mm) or vermiculite at the following matric potentials: -0.03 MPa, -0.2 MPa, -0.81 MPa and -1.6 MPa. The soil was packed at a bulk density of approximately 0.8 g/cm^3.The duration of the growth period was 96 h when root and shoot lengths were measured with a ruler.

2.2. X-ray computed tomography

3D volumetric images of seeds growing in soil and vermiculite at a matric potential of -0.03 MPa for one day at 20 ºC in darkness (Figure 1) were obtained using a Metris X-Tek HMX CT scanner with a Varian Paxscan 2520 V detector and a 225 kV X-ray source (http://www.xtekxray.com/products/systems.html#hmx). The energy of the beam was 145 kV and the current was set to 201 µA and 2885 projections were acquired using a molybdenum target. For reconstruction the Metris software CT Pro v2.0 was used. This software employs a filtered back-projection algorithm. A resolution of 15 µm (isotropic voxel size) was attained. Root-particle contact was analysed using VGStudio MAX v2.0 (http://www.volumegraphics.com). For segmenting root volume and calculating root surface and contact area, an advanced calibration and 3D volume segmentation tools, which identify and extract voxels belonging to calculated ranges of greyscale values (representing root, air and growing medium), were used. The surface area of the root and the contact area were determined as a result of calibrating and segmenting in 3D relevant volumes of interest. In order to measure the contact surface area of root and solid particles, voxels corresponding to the root volume and adjacent to voxels representing air phase, were subtracted from the volumetric region representing surface area of the root.

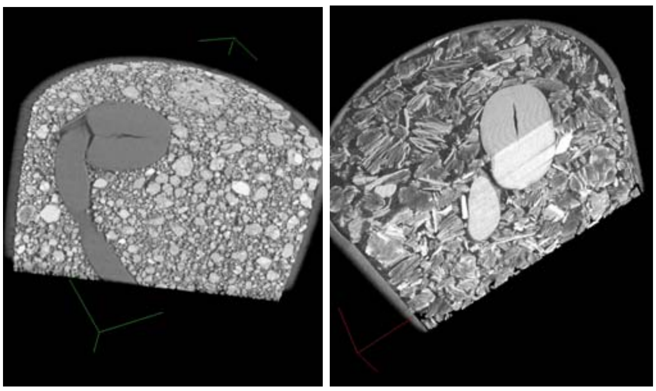

Figure 1. 3D CT images show *Lupinus angustifolius* in soil (left) and in vermiculite (right)

3. RESULTS

The root elongation rate of maize and lupin decreased with decreasing matric potential in both soil and vermiculite (Figure 2). Maize showed sensitivity to the growth material at matric potentials greater than -1.6 MPa. The root elongation rate was higher in soil than in vermiculite (Figure 2). Lupin elongated faster in soil at a matric potential of -0.2 MPa, but not at other potentials.

Preliminary investigations of root-particle contact of maize and lupin in soil and vermiculite at -0.03 MPa showed greater relative contact in soil than in vermiculite. Lupin showed a greater relative root particle contact than maize (Figure 3).

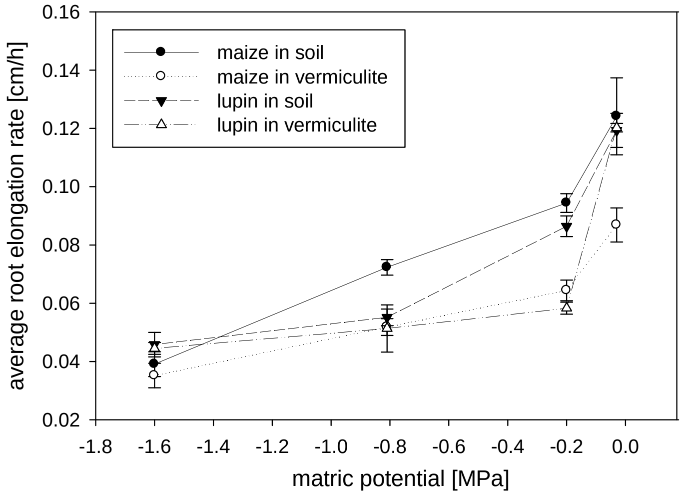

Figure 2. Average root elongation rate [cm/h] of maize and lupin in soil and vermiculite after 96h growth

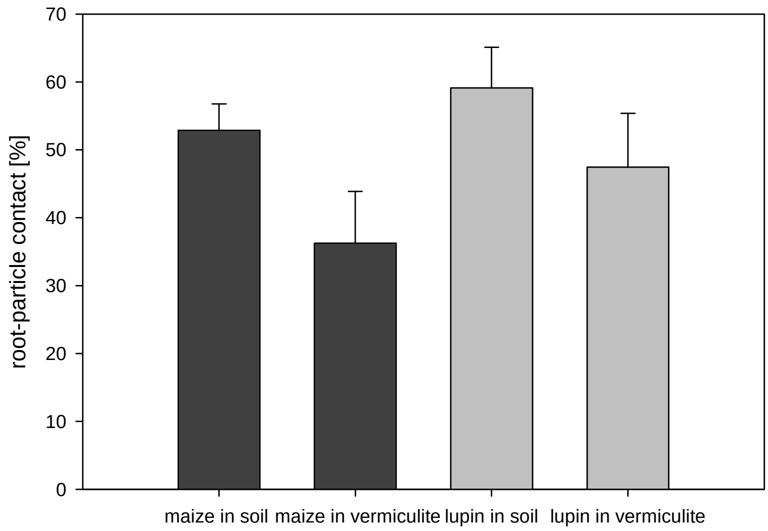

Figure 3. Preliminary results of relative root particle contact of maize and lupin in soil and vermiculite -0.03MPa

4. DISCUSSION

In this study the effect of matric potential, growth medium and plant species were investigated. Matric potentials in a range from field capacity to wilting point were chosen. Maize and lupin showed a decrease in root elongation rate with decreasing matric potential, these findings are similar to the findings of Sharp et al. (1988). Lupin is known as drought resistant by the adaption of drought escape (French and Buirchell, 2005), which allows the plant to reproduce in a short growing season before the soil dries. In this experiment dry condition were applied from the start which might explains although lupin is known as drought tolerant the root elongation rates were slower than for maize. Maize root elongation rate was greater in soil than in vermiculite at all matric potentials greater than -1.6 MPa. That leads to the conclusion, that the soil provides better growth conditions than vermiculite at a matric potential above wilting point. The differences in elongation rate decreased with decreasing matric potential between soil and vermiculite for maize. It seems that the advantage for maize root growth of soil increases with increased matric potential. Lupin on the other hand showed the greatest divergence in root elongation between soil and vermiculite at a matric potential of -0.2 MPa and it is smaller at higher or lower matric potentials than -0.2 MPa. Overall the differences in root elongation of lupin in soil and vermiculite are less than for maize. Lupin seems to be less sensitive to the growth material than maize, which might be expected due to the greater drought resistance of lupin.

Preliminary results of this study have shown greater root-particle contact in soil than in vermiculite. Maize and lupin elongated faster in soil than in vermiculite, therefore we think that root-particle contact is important for root growth. Thin sections have shown a greater root-soil contact was correlated with water uptake. The water uptake was highest at an intermediate bulk density. No mechanical impedance or aeration problems exist in very loose packed soil, but the uptake per unit root length might be reduced due to a combination of insufficient root-particle contact and a reduce hydraulic conductivity (Veen et al., 1992). Vermiculite probably had a lower hydraulic conductivity and incomplete root-particle contact compared to soil. Another study (unpublished data) where maize and lupin were grown in humid air above salt solutions at osmotic potentials of a range from -0.03 MPa to -1.6 MPa indicated the importance of contact between root and growing medium. Roots grown in air showed slower elongation rates than in vermiculite and soil. These results support our hypothesis that a greater root particle contact in soil than in vermiculite leads to faster root elongation rates. Verification of the method for investigating root-particle contact is necessary to confirm the preliminary results of this study. In future the quantification algorithm of root-soil contact area will be verified by using 'phantoms' of known geometry to overcome uncertainties and errors in the developed segmentation procedure for root material from air and solid phases.

5. ACKNOWLEDGEMENTS:

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