Towards an effective characterization of root electrical properties: a spectroscopic approach

Motivation

The application of geophysical methods to root investigation is increasing in recent years because of the limitations associated with the use of traditional methods (root excavation, moistnoment, microtrenching, etc.). Point sampling is only partially satisfactory as a result of the spatial variability and dynamics of the root zone. Geophysical methods address these limitations by offering high resolution and non-invasive approaches to root investigation. Among various geophysical methods used for root studies, frequency electrical methods are of great interest because they target direct electrical response of the roots. Recent studies (Weigand and Kemna 2017; Mary et al. 2017) have reported a low frequency polarization of root systems and have shown that spectral induced polarization and electrical impedance tomography holds a promising future for root system characterization. Despite these significant improvements, there is still a knowledge gap regarding the electrical response of fine roots at the segment scale which is essential to account for the effect of roots in the estimation of soil moisture content of forested soils.

Methods

Figure 2. Measurement Set-up.

- The setup is mounted on the sample holder, in a channel filled with conductivity gel.
- The electrodes are retrieved from the channel such that contact with root is only established through the gel.
- Plants grown in sand: 32 plants were sampled, 16 maize (16-plants) and Brachypodium (16-plants).
- Root diameter measured with a digital caliper.
- Impedance and phase measurement on primary roots (at maturation zone).
- Root resistivity is expressed as \( \rho_r = \frac{Z_r \pi D_r^2}{4L_r} \).
- Calibration of measurement set-up.

Figure 4. Validation of measurement set-up.

(a) The impedance values of three ideal resistors and conductivity gel compared to that of the root. The measured impedances of the resistors matched their true values as expected but they exhibited the EM coupling effect at frequencies above 10 kHz. The root polarized strongly with a peak of 320 mrad. The conductivity gel showed a phase response of -2.5 rad compared to that of the root. (b) The phase response of the resistors and conductivity gel compared to that of the root. The resistors showed the phase response. (c) Phase response at low frequencies below 100 Hz, showing a strong polarization response of the root at all lengths scales.

Figure 5. Intra-species variability. (a, b) The resistivity and phase responses of 4 maize plants (A, B, C, and D) of same age (27 days) grown under the same conditions are compared. They showed similar electrical signatures with minor variations.

Figure 6. Inter-species variability. Comparing average electrical responses of several maize and Brachypodium plant roots at 8 days.

(a) Average impedance of maize root compared to Brachypodium root. Maize showed lower impedance (315 KΩ) with standard deviation of 74 KΩ, while that of Brachypodium was higher (3.7 MΩ) with standard deviation of 0.9 KΩ. (b) Resistivity values of both species showing only minor variations. (c) Phase responses of both species.

- Strong variation is observed between both species.
- Brachypodium roots polarized more strongly with a peak value of 700 mrad compared to maize root with a polarization peak value of 410 mrad.

Results

- Measurement of current in roots.
- The root is mounted on the sample holder, in a channel filled with conductivity gel.
- The electrodes are retrieved from the channel such that contact with root is only established through the gel.
- Calibration of measurement set-up.

Figure 8. Microscopic section of maize and Brachypodium primary roots at 24 days, sectioned at the maturation zone with the presence of root hair.

- Brachypodium root is smaller in size with densely packed cortex cells.
- Maize is larger in size, with cortex cells less densely packed.

Figure 9. Current passage in roots at low and high frequencies (use Bars et al. 2016).

- At 12 kHz, we assume that current will pass through all the roots (Bars et al. 2016 and Reps et al. 2020).

Figure 10. (a) Root system with horizontal electrodes (green line) showing water uptake pattern

- Normalized effective conductivity (real and imaginary part) spectra for resistive soil (blue) and conductive soil (red) along with original root segment spectra (in black). The green arrow indicates a shift in spectra phase due to soil contrast.

Conclusions

- Root differentiation from soils
  - The polarization range for various earth materials fall within 0.2-20 mrad
  - The results suggest that root segments can be identified and distinguished based mainly on their stronger polarization response
  - Modeling result show that the imaginary part of conductivity is more effective in capturing key properties of different soil-root systems, e.g., root age and soil wetness.
- Root properties
  - Electrical response of roots depend mainly on their age and anatomy
  - Intra- and inter-species variability
  - Different plants of each species studied showed similar response with minor variations.
- Maize and Brachypodium roots showed unique electrical signature which is largely dependent on their anatomy

References
