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Decreasing the scattering of root electrical capacitance

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The measurement of electrical capacitance of root in soil (CR) is a useful method for estimating the root system size (RSS) in situ. By fixing one electrode to the plant stem, embedding the other in the soil, and connecting them to a capacitance meter operating with a low-voltage alternating current (1V, 1 kHz AC), the measured CR is directly correlated with root dry mass, root length and root surface area. CR is formed by the polarization and relaxation phenomena of living root membranes and cells, leading to changes in the amplitude and phase of the applied AC signal.

The main limitation for the generalization of the capacitance method is the sensitivity of CR to edaphic factors, such as soil water saturation, ionic status and soil texture. In most practical measurements, correlations of CR and RSS are often rather weak. This weak relationships could be partly due to the variable energy-loss rate indicated by the dissipation factor (DF). CR proved to be a poor predictor of RSS, particularly when the measurements were performed not in hydroponic or mineral substrates, but in more complex and heterogeneous natural soils. The reason for this is that, while ideal physical capacitors store energy electrostatically with an infinitesimal effective energy loss, root tissue – being an imperfect dielectric – acts as a poor capacitor. Soil constituents, particularly colloids, also possess dielectric character, making the root–soil–electrode system more complicated electrically.

In order to study the scattering of CR–RSS regressions, values of CR and the associated DF were measured in an experiment with six plant species grown in pumice medium, arenosol and chernozem soil. It was hypothesized that the low efficiency of CR measurements and the weak CR–RSS relationship are at least partly due to the variability of DF, which influence CR. Therefore, the measurement of DF when the CR method is applied and the use of DF to modify CR data will presumably contribute to enhancing the predictive capability of CR for RSS. A modified root–soil capacitance, CDF, was calculated from each CR/DF pair according to the formula CDF = CR·(DF/DFmean)α by estimating α with a standard nonlinear minimization of the sum of squared residuals for CDF–RSS regressions.

The results showed, that the capacitive behavior of the medium improved (mean DF decreased) but fluctuated increasingly as the plant growing substrate became more complex. The mean DF values in plant–substrate systems were chiefly determined by the plant and were the most variable in chernozem soil. This strengthening substrate effect on CR measurements appeared as a decreasing trend in the R2 values obtained for the CR–RSS regressions. The regression slope was influenced by plant species and medium, while the y-intercept differed only between substrate types. The proposed use of CDF in place of CR could significantly improve the R2 of CDF–RSS regressions, particularly in chernozem soil (R2 increased by 0.07–0.31).

Our main conclusion, that the application of CDF will provide more reliable and accurate RSS estimations and more efficient statistical comparisons.