

# Characterization of Tree Roots by Electrical Impedance Spectroscopy

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# Outline

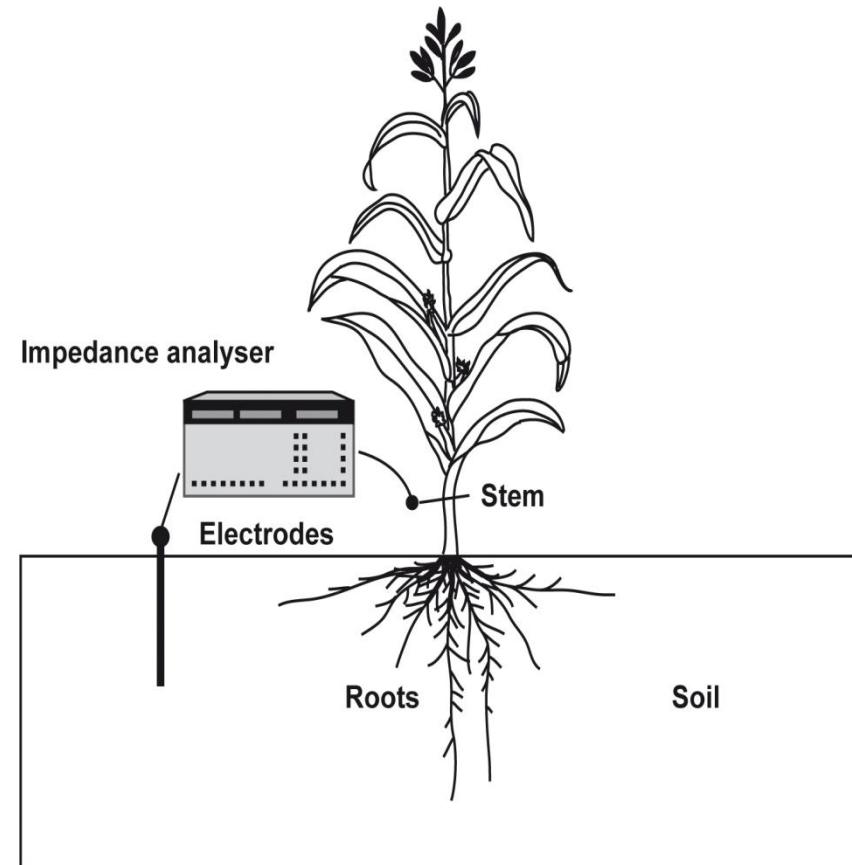
- Motivation and basis for EIS spectroscopy
- Some EIS results for tree roots
- Summary



Mycorrhiza. Photo: Anna Korhonen and Marja Roitto.

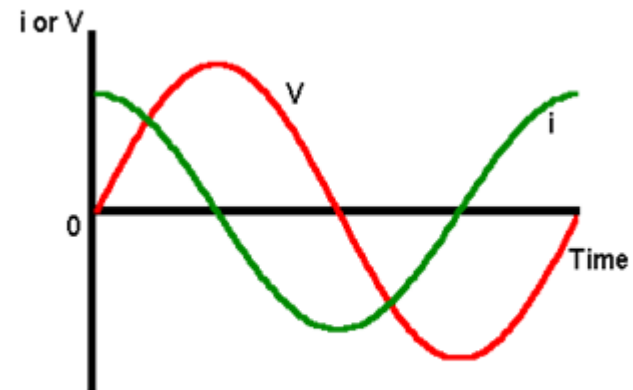
# Motivation

- Root biomass
- Root growth dynamics  
(length, volume, surface area)
- Absorbing root surface area



# Electrical impedance spectroscopy (EIS)

- current:  $i(\omega)$
- voltage:  $v(\omega)$
- phase:  $\phi(\omega)$
- $\Rightarrow$
- impedance:  $Z(\omega) = \frac{v(\omega)}{i(\omega)}$



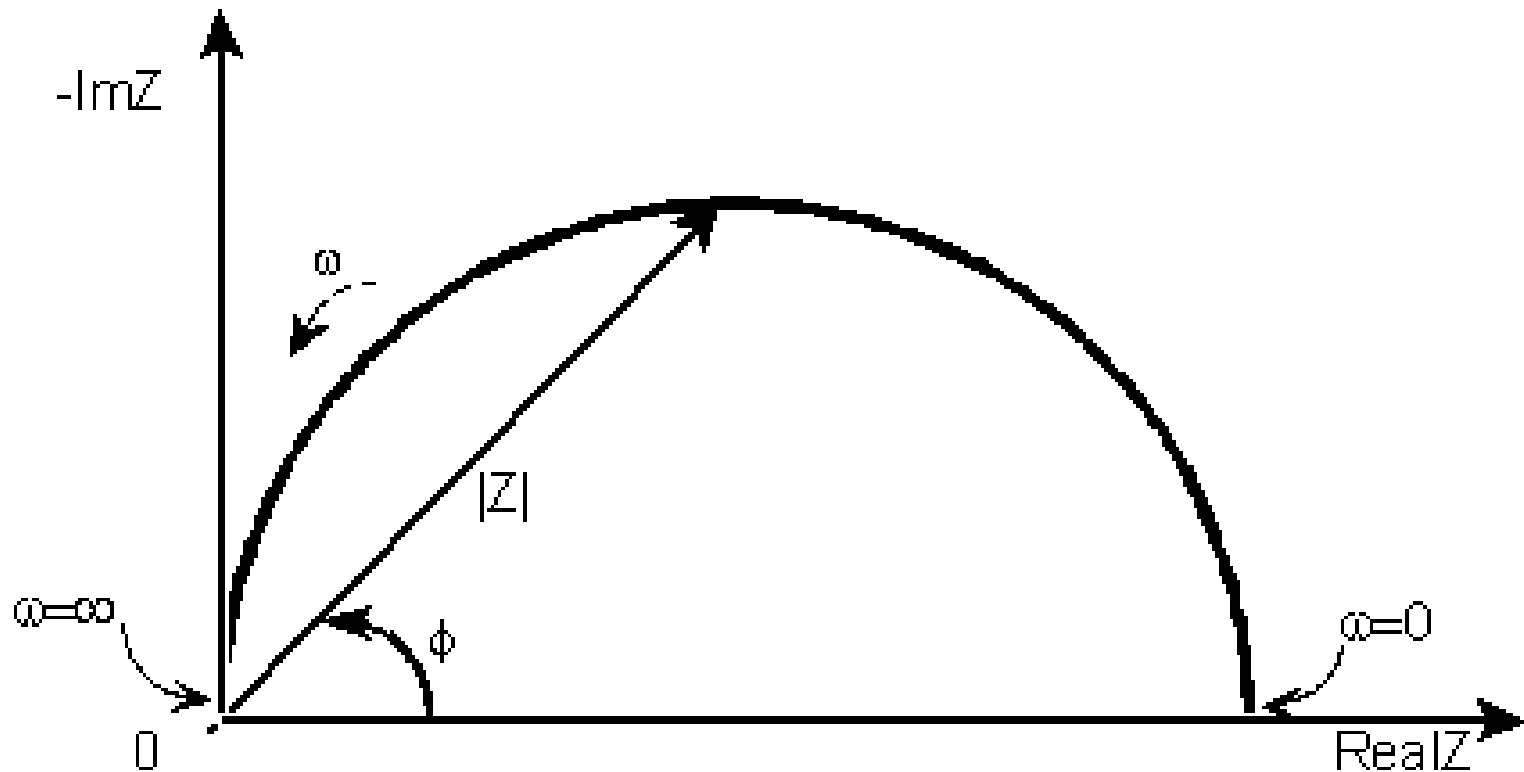
E/I response for a capacitor ( $\phi = -90$ )

$\Rightarrow$  complex impedance:

$$Z(\omega) = Z_{\text{real}}(\omega) + j \cdot Z_{\text{imag}}(\omega)$$

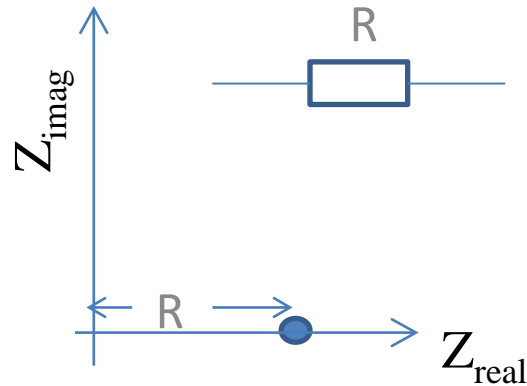
$\Rightarrow$  impedance phase angle ( $\theta$ )  
and modulus ( $|Z|$ )

Impedance Spectrum (Wessel diagram) is formed of complex impedance at different frequencies

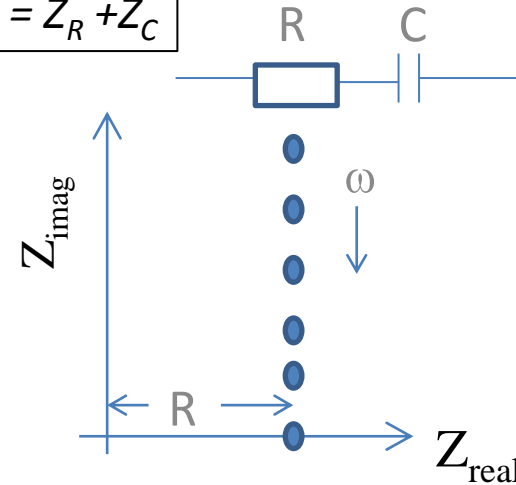


# Basic electric models and their complex impedance

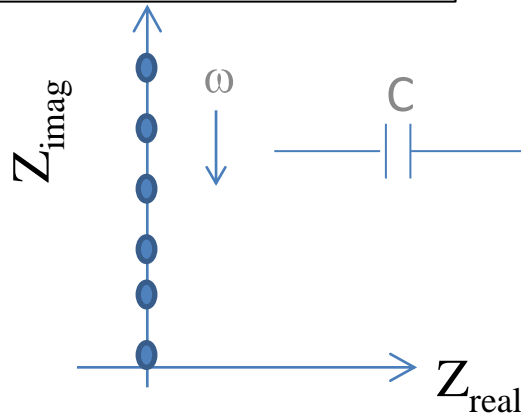
Resistance ( $R$ ):  $Z_R = R + j*0$



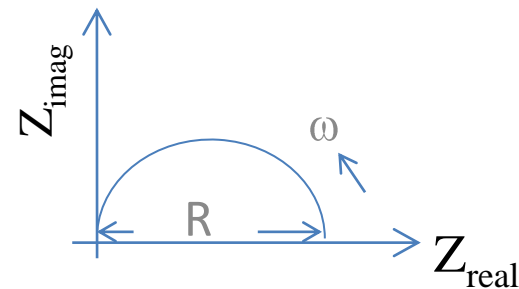
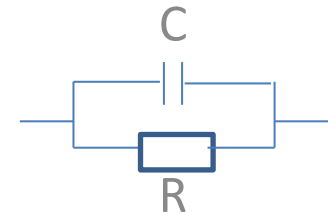
$Z_{RC} = Z_R + Z_C$



Capacitance ( $C$ ):  $Z_C = -j/\omega C$



$$Z_{R||C} = \frac{Z_R Z_C}{Z_R + Z_C}$$



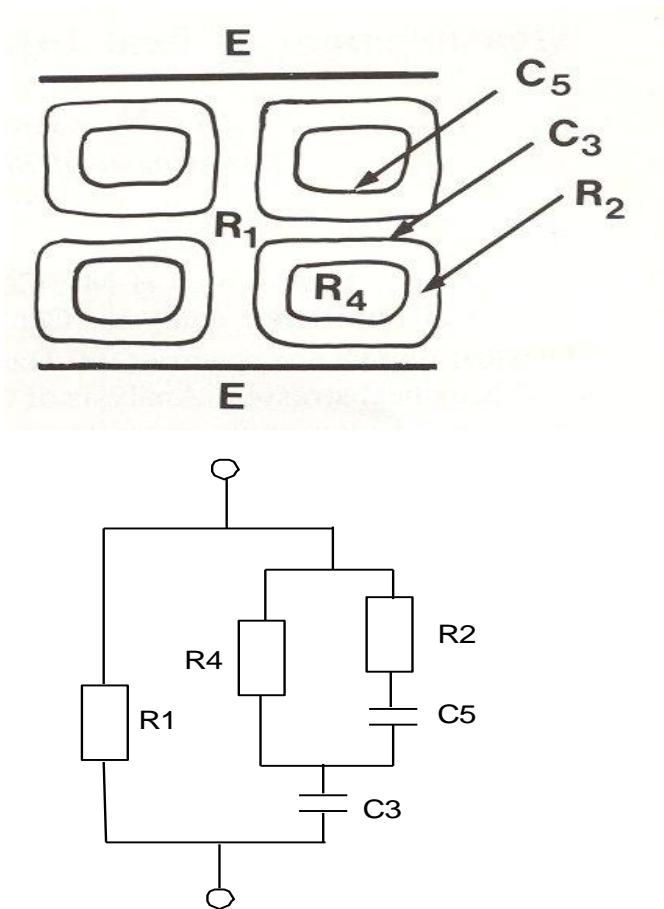
# Dispersion ranges

- $\alpha$ –dispersion from a view Hz to 10 kHz
- $\beta$ –dispersion from 10 kHz to 100 MHz
- $\gamma$ –dispersion from 100 MHz to 100 GHz

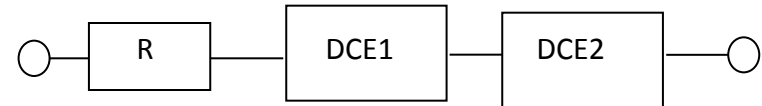
# Electrical models

## Lumped models

\* e.g. double-shell model

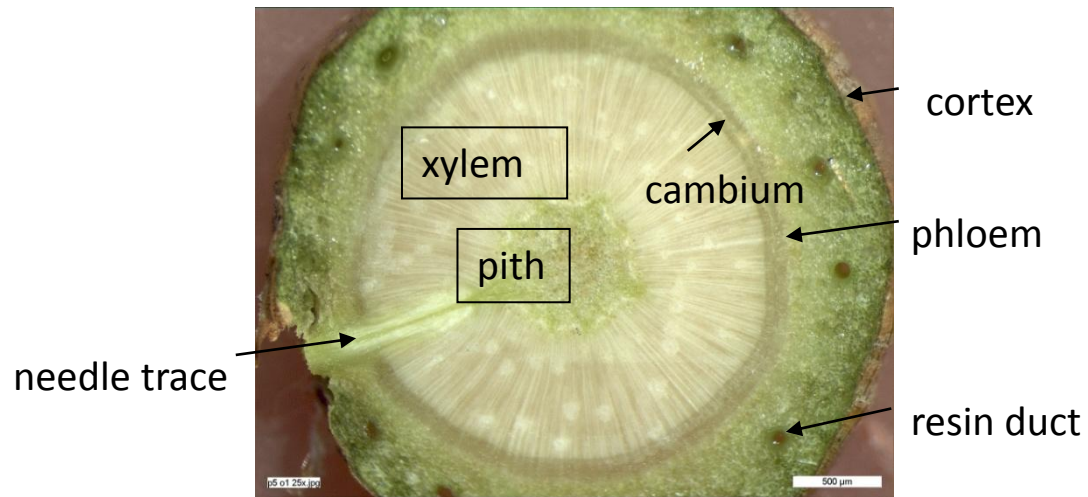
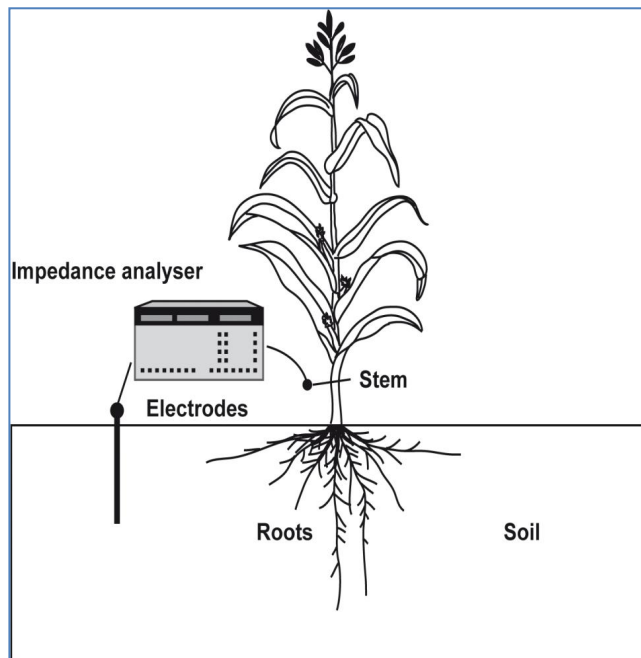


## Distributed models

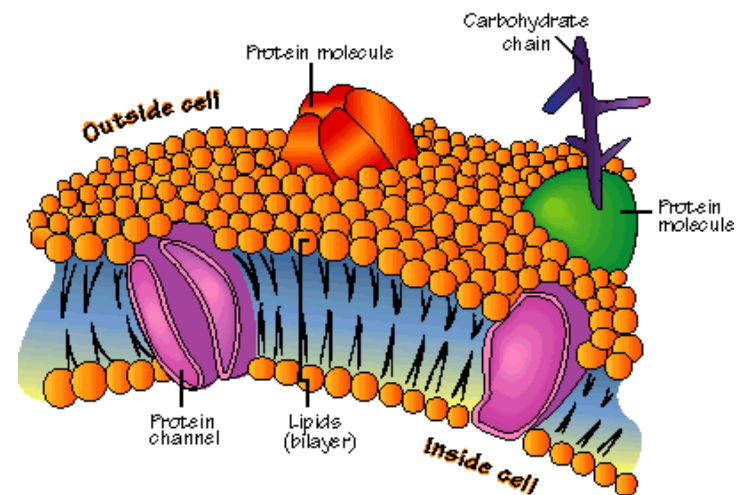
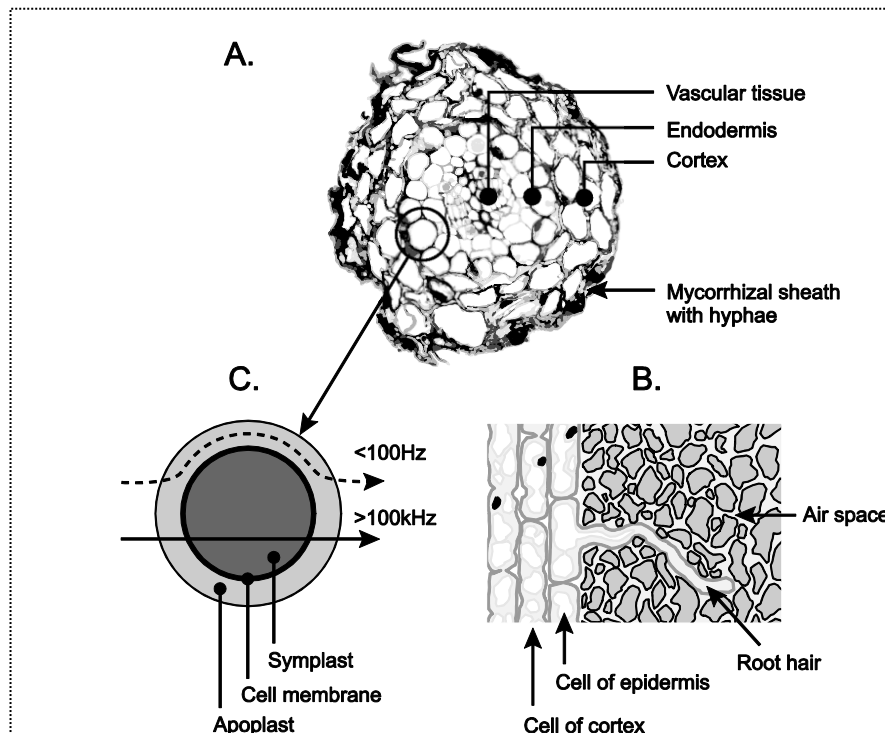


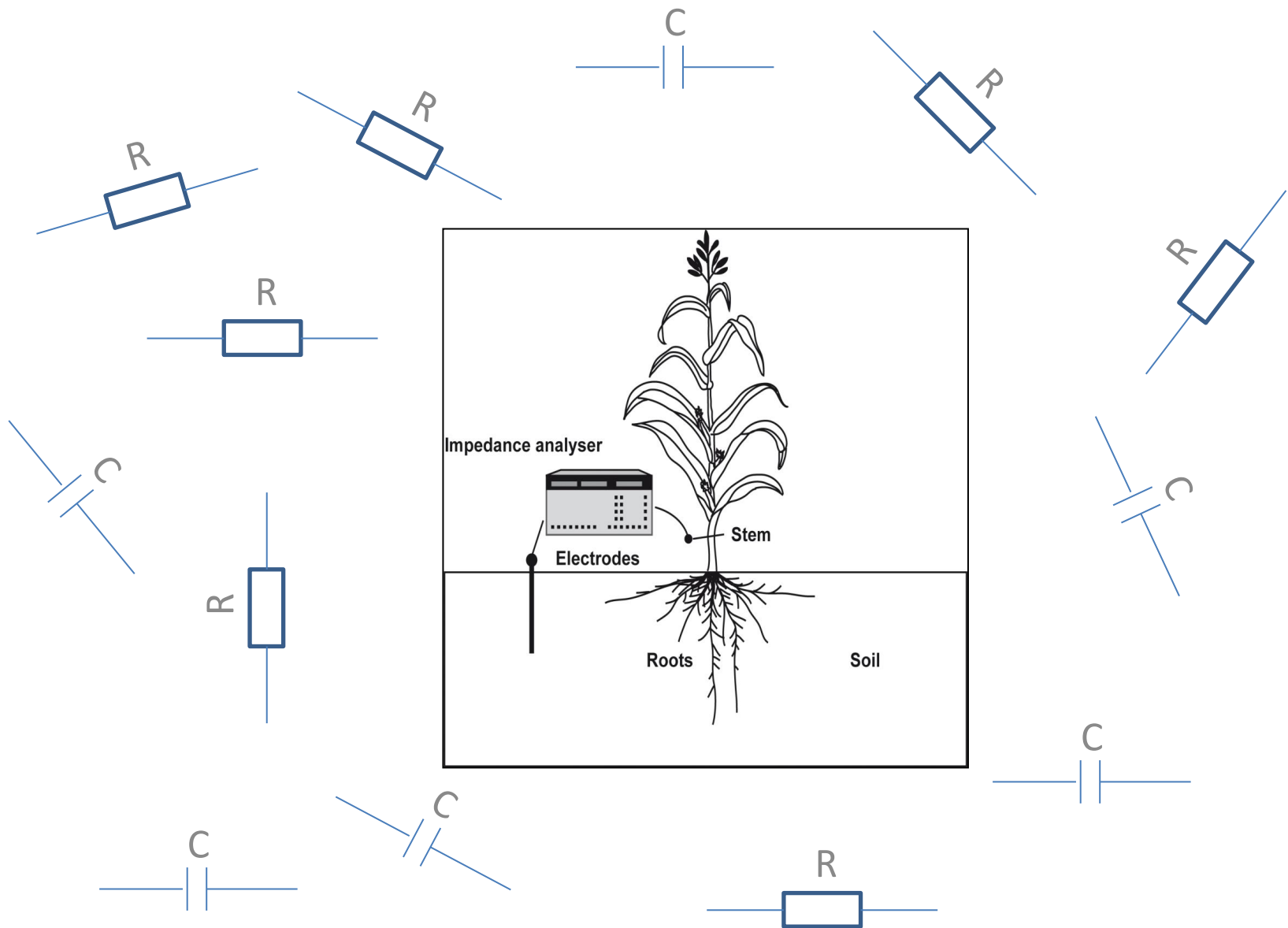
$$Z = R + \frac{R_1}{1 + (i \cdot \tau_1 \cdot \omega)^{\psi_1}} + \frac{R_2}{1 + (i \cdot \tau_2 \cdot \omega)^{\psi_2}}$$





(Photo by Sirkka Sutinen)





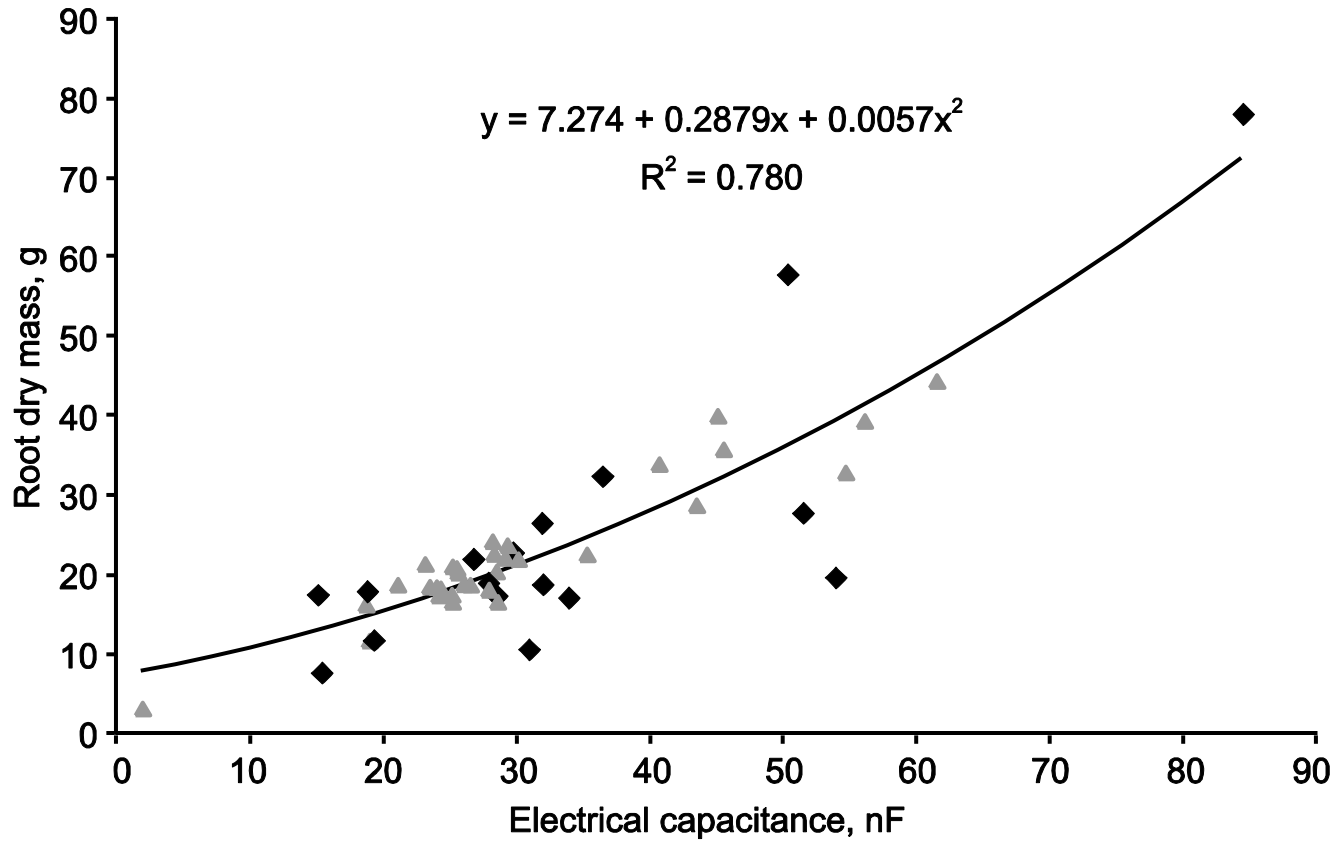
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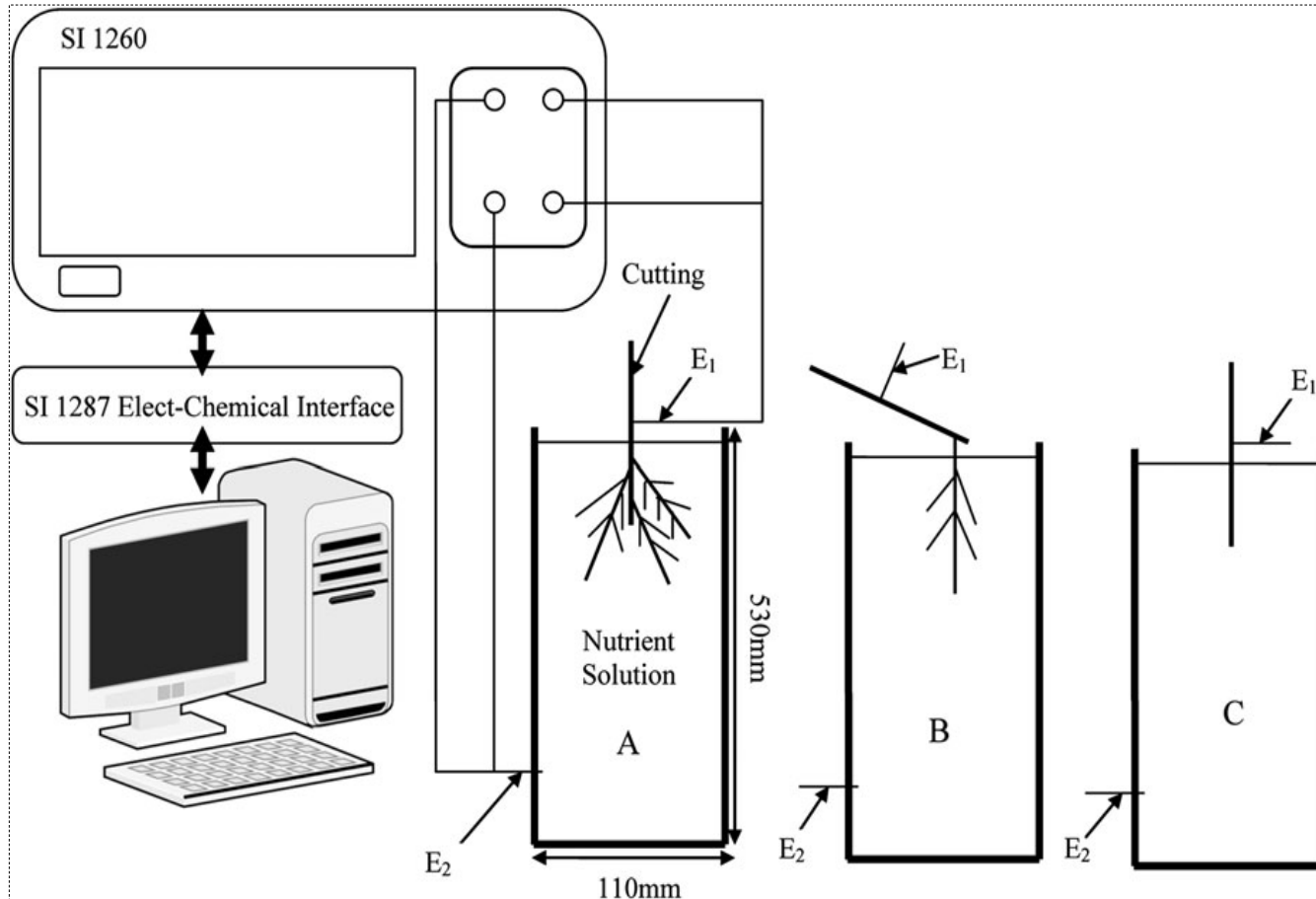


Mycorrhiza. Photo: Anna Korhonen and Marja Roitto.

# First-and third-year hybrid poplars (f=1 kHz)

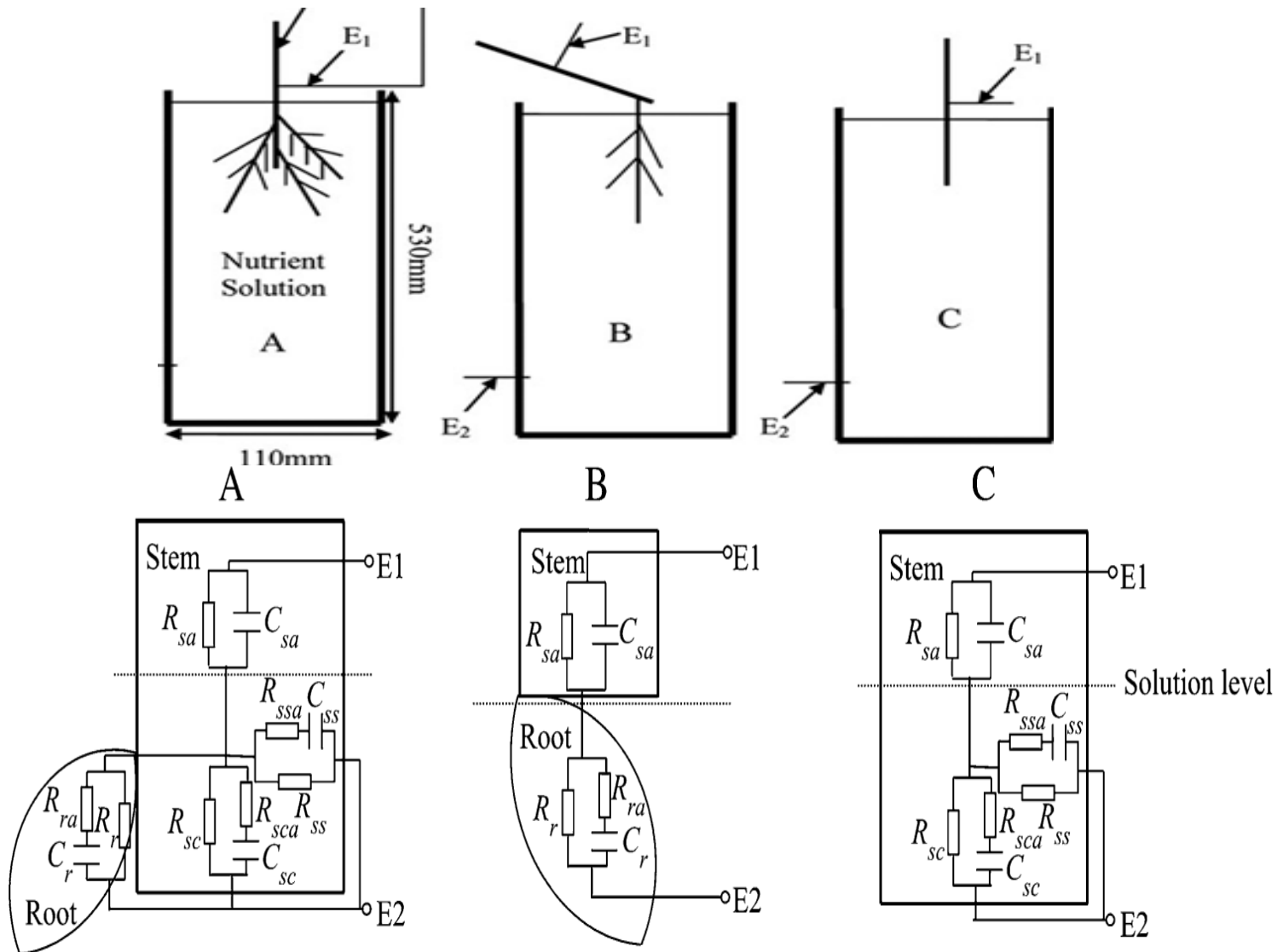


# EIS of willow roots in nutrient solution



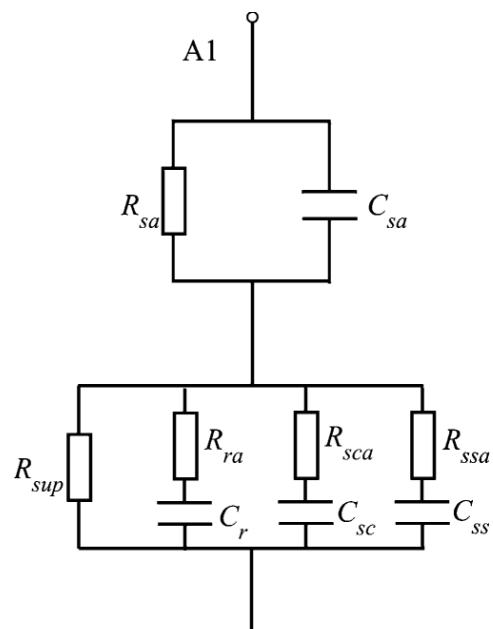
$E_1$  and  $E_2$  are electrodes

# Electric models

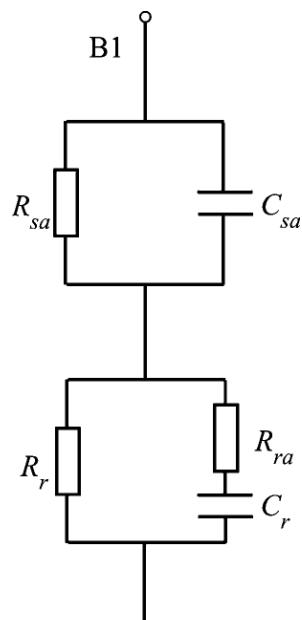


$E_1$  and  $E_2$  are electrodes

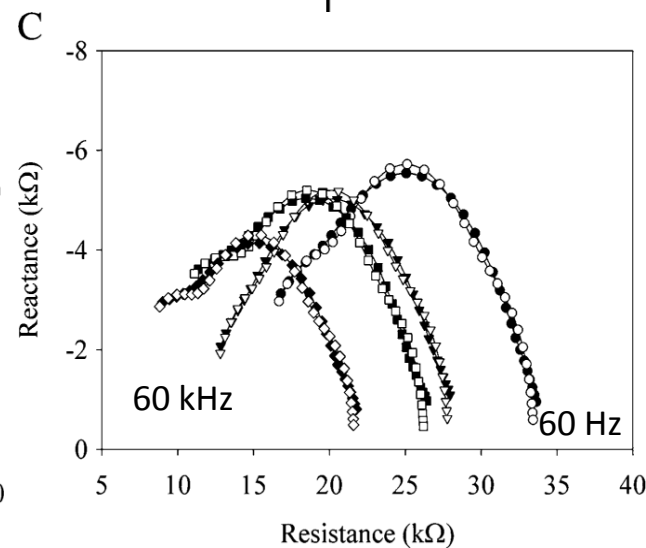
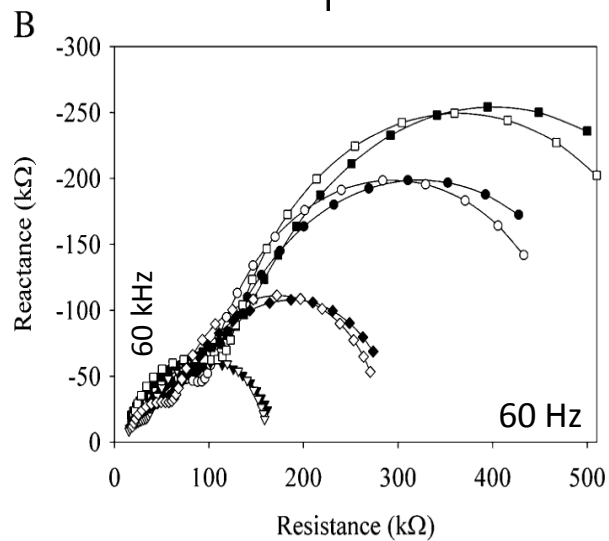
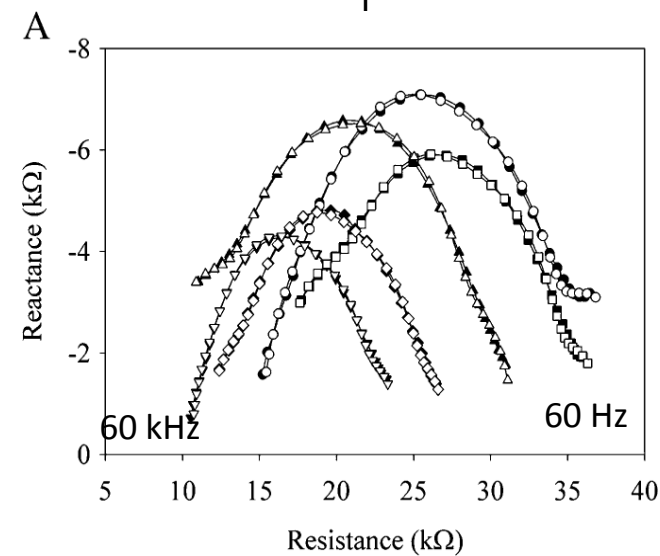
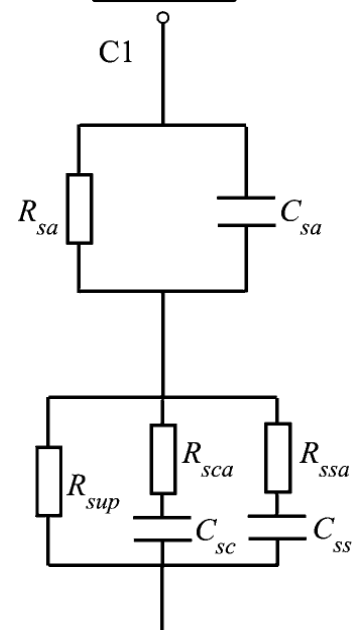
Stem and root



Root

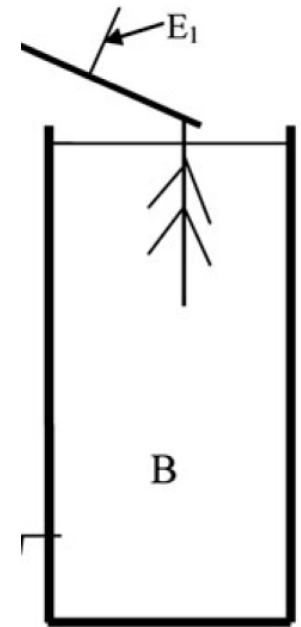
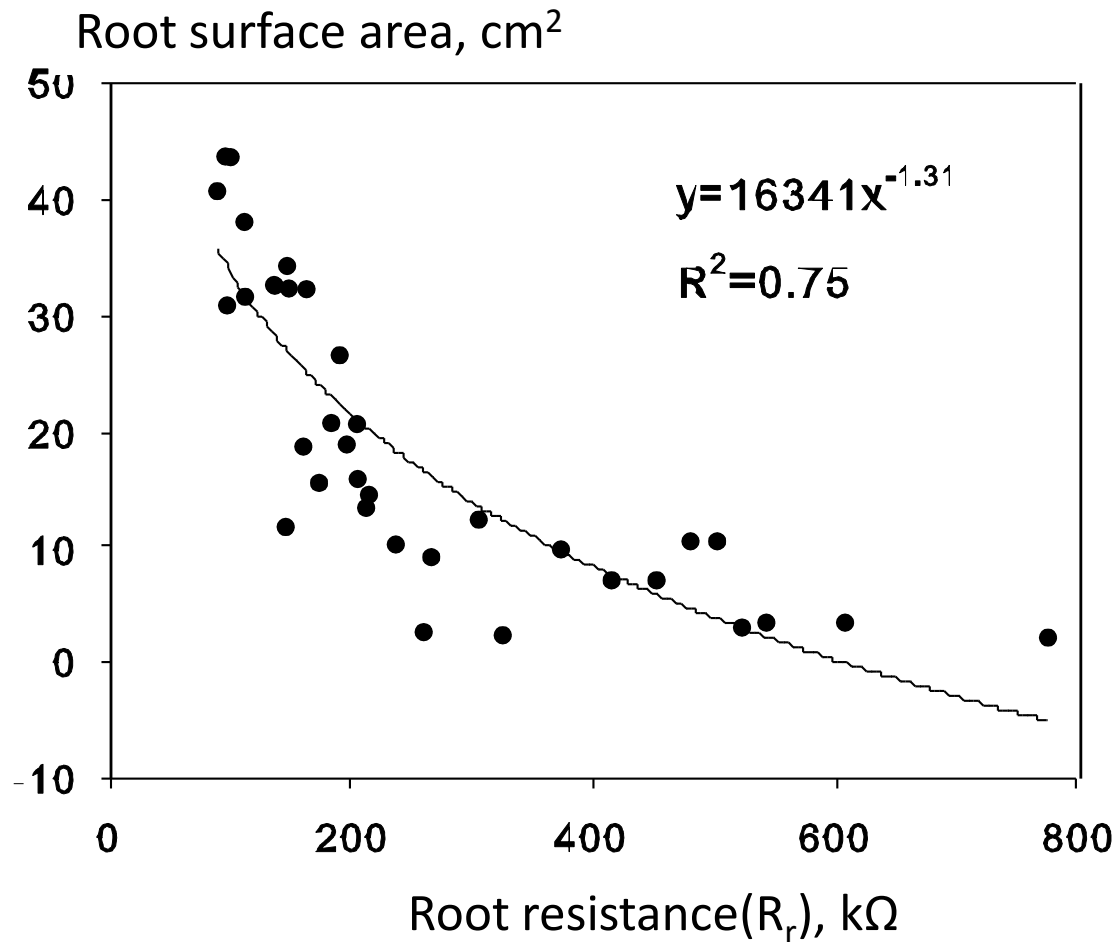


Stem



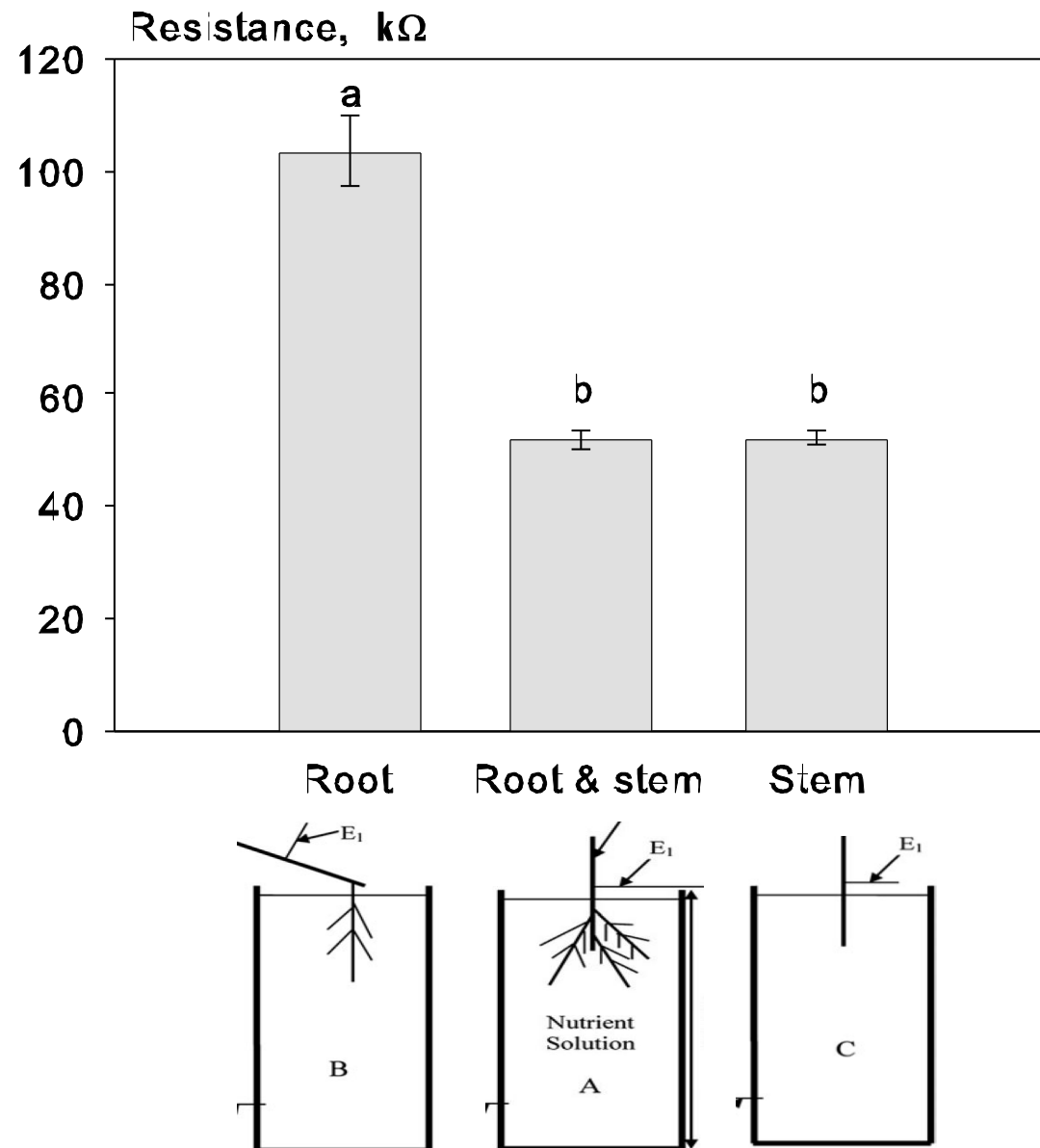
**Filled symbols:** Experimental data. **Open symbols:** Model fit.

# Root resistance of willows in nutrient solution

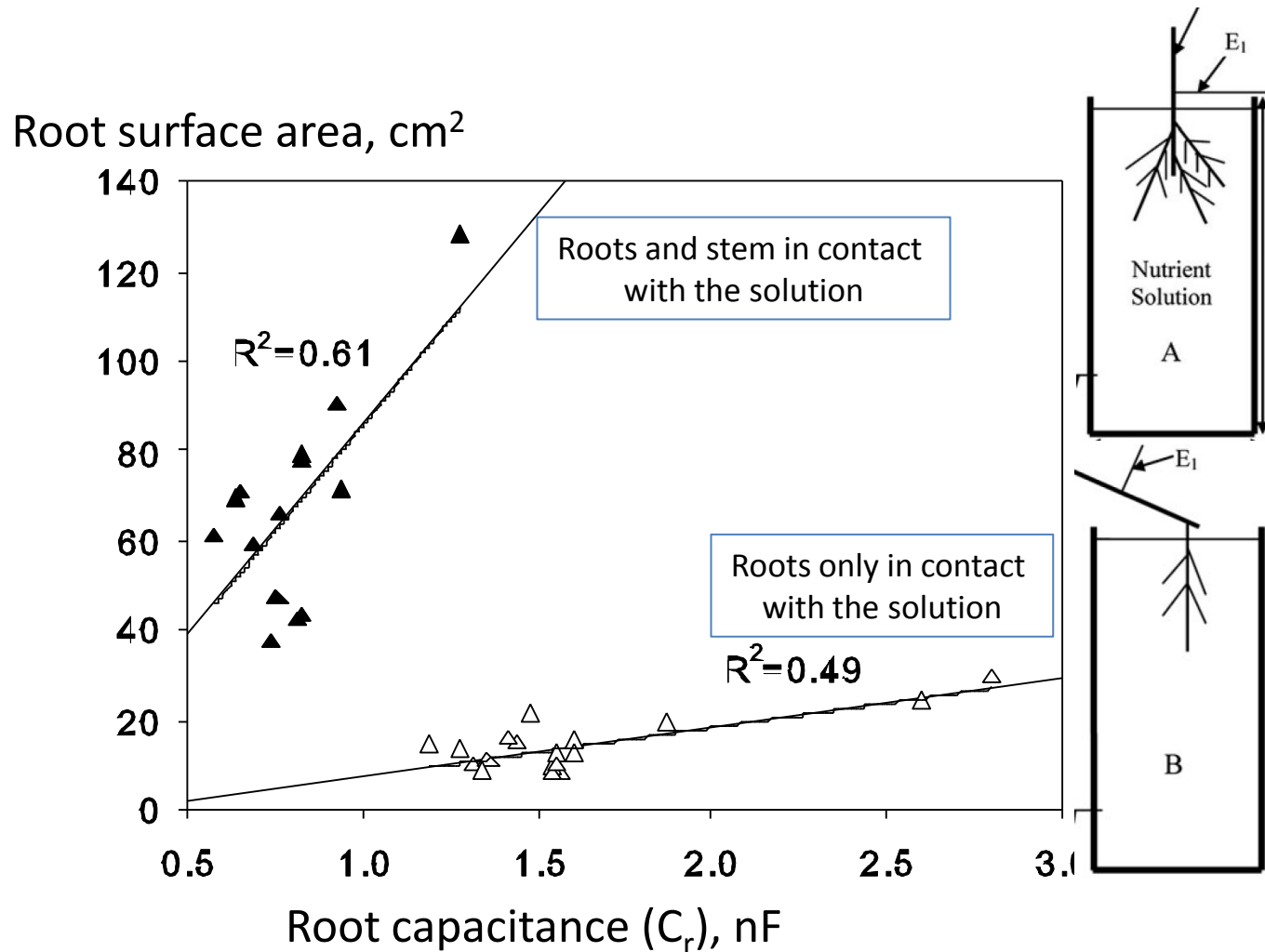




# Resistance of root, root & stem and stem in contact with the solution



# Root capacitance of willows in nutrient solution



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Mycorrhiza. Photo: Anna Korhonen and Marja Roitto.

# Summary

- Electric models fit well with EIS experimental data of willow cuttings in hydroponics
- Stem had a strong effect on sensitivity (especially root resistance) to detect root surface area
- Root capacitance correlated with root surface area



*Thank you*

Midnight moon in midsummer