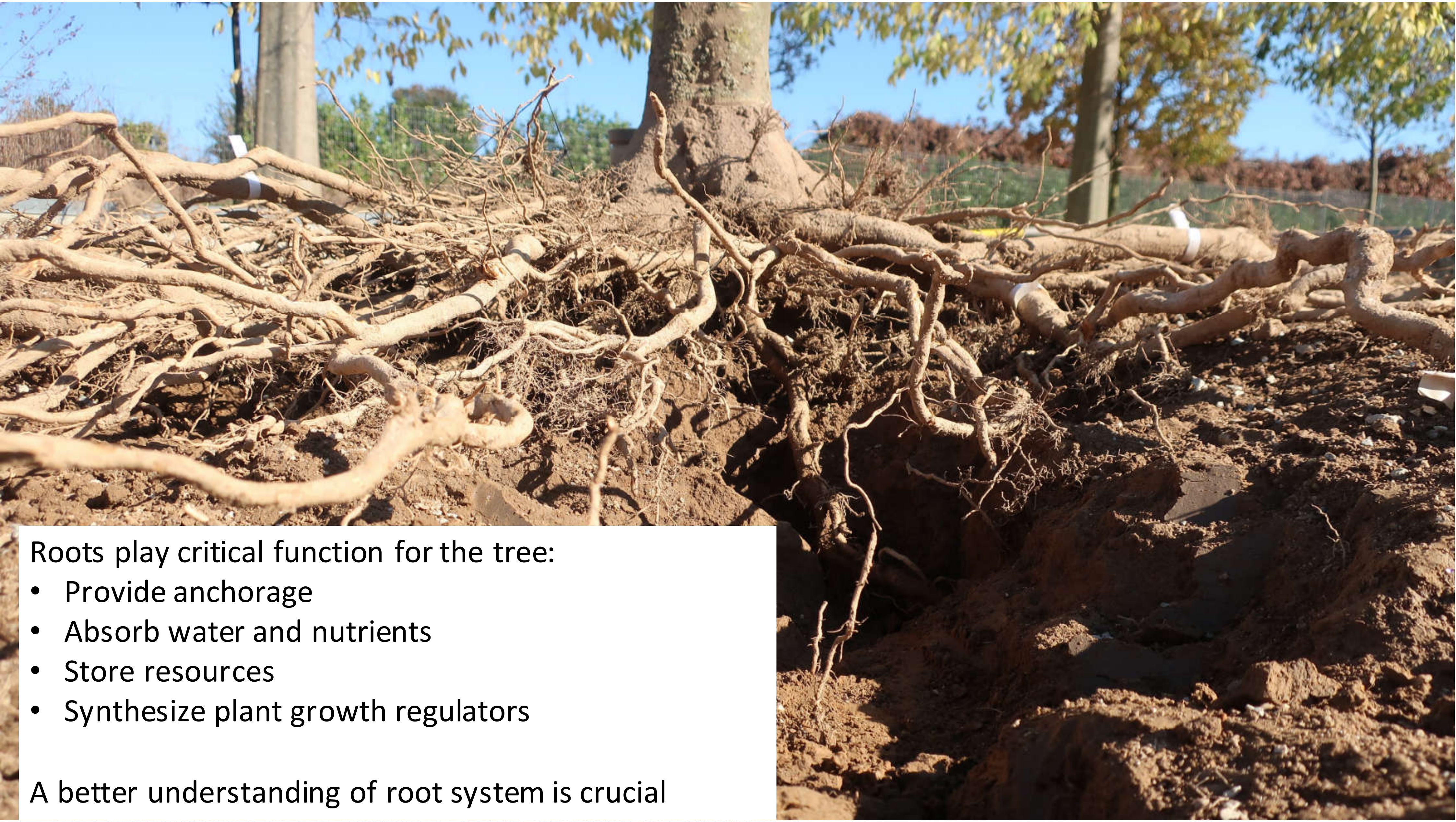
Evaluation of different non-invasive methods for root research in paved sites.

Sebastien Comin, Piero Frangi, Irene Vigevani, Francesco Ferrini, Alessio Fini*



Roots play critical function for the tree:

- Provide anchorage
- Absorb water and nutrients
- Store resources
- Synthesize plant growth regulators

A better understanding of root system is crucial

Because roots are out of sight, they are often out of mind

Roots constrained by a stone wall

Because roots are out of sight, they are often out of mind

Cutting roots for repair/expansion of below ground services…
…and for new constructions

Roots can displace pavements..

..but cutting roots to repair pavements may have long term consequences

Consequences of root severance

Mild but chronic decline in CO_2 assimilation, especially on sensitive species

Up to 50% reduction in the bending moment need to reach a flare inclination of 0,2° using a static pulling test

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Evaluating the effects of trenching on growth, physiology and uprooting resistance of two urban tree species over 51-months

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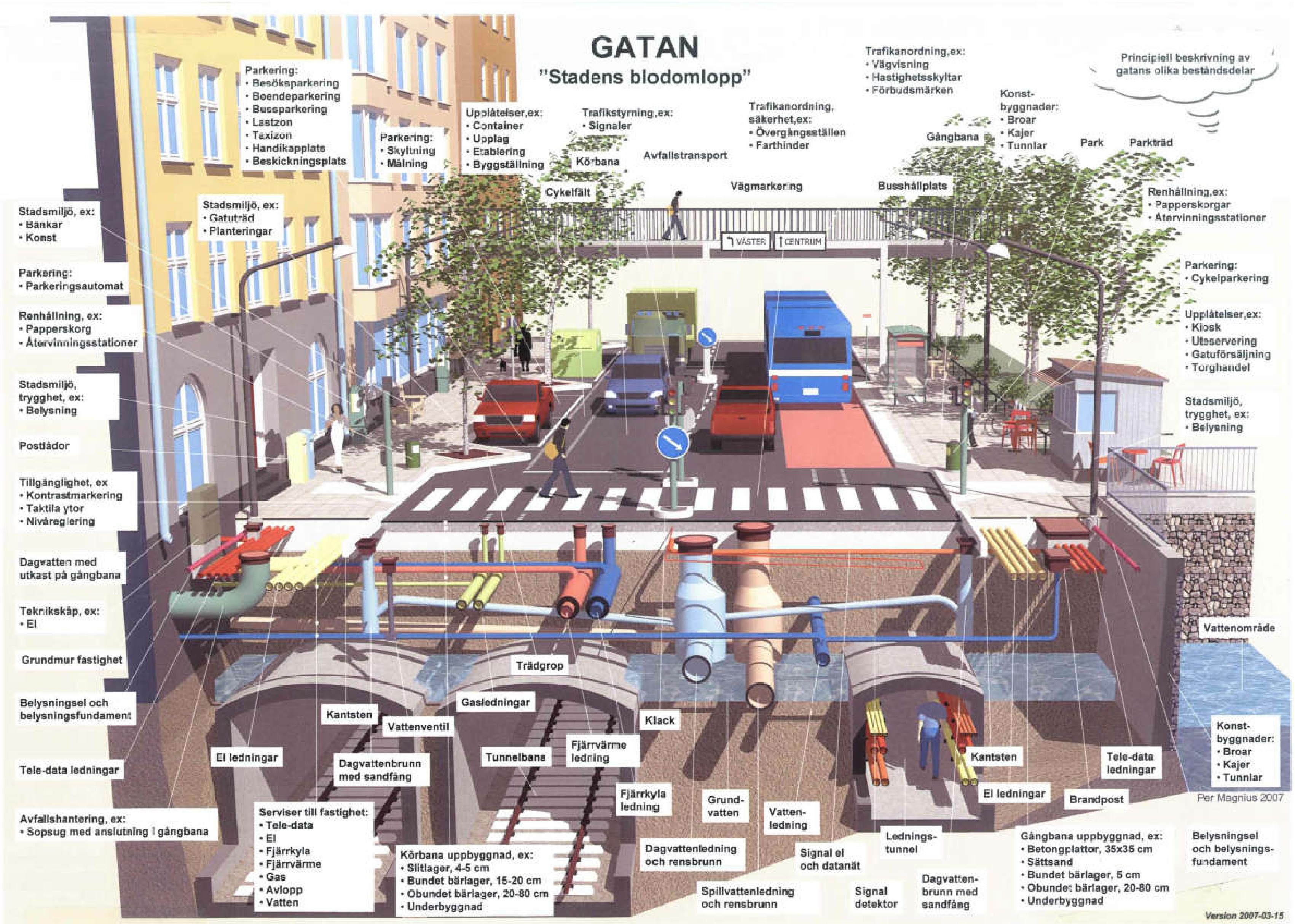
Trees predispose to decline and uprooting

Consequences may reveal after 10 years



Intense conflicts between roots and the grey infrastructure occur in densely built urban settings, the latter having often the precedence over tree preservation

O. Stal

Knowing where roots are may help preserving them

Methods for root detection

Indirect methods: allow the study of the root system without the need of physically accessing it

Direct methods:

- Excavation of the whole root system
- Measurements on uprooted trees (naturally or artificially pulled, Koizumi et al., 2007)
- Trenching
- Soil coring
- Soft dig (AirspadeTM; Suction excavator)

- Not well perceived in urban sites
- Not replicable over time
- Require pavement removal

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Non-invasive methods for the investigation of trees' root system in the urban environment

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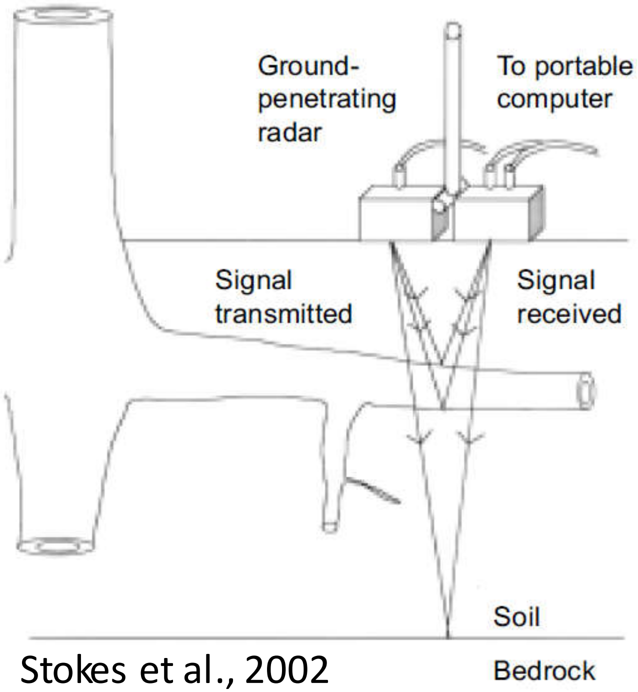
Keywords: "root system investigation", "non-invasive methods", "non-destructive methods", "tree root system analysis", "geophysic techniques", "ground penetration radar", "root 3D architecture", "urban tree root system", "electrical measurements", "electrical resistivity tomography", "root distribution", and "root biomass analysis".

9034 papers → Relevancy check → **69 papers**

Ground Penetrating Radar | **Electrical Resistivity Tomography** | **Earth Impedance Method** | **Sonic tomography**



Stokes et al., 2002

Ground-Penetrating-Radar (GPR)

Theory

- GPR is made of an antenna and a receiver.
- The antenna releases short pulses of electromagnetic waves downward into the soil
- The wave speed depends the dielectric constant of the material crossed
- While going downward in a heterogenous media such as rooted soil, a part of the wave is reflected
- The amount of reflected wave depends on the difference in the dielectric constant between the materials crossed
- The receiver perceives the reflected waves and calculates the two-way travel time of the wave from the antenna to the body which causes the reflection, and back to the receiver
- The depth of the point of reflection can be calculated as speed * half of the two-way travel time

Dielectric constant is up to 22 for dry wood, but 80 for water.
Well-hydrated, healthy roots can be theoretically detected.
Detection is easier in soil with low water holding capacity and when the soil is dry.

Material	Dielectric constant	Electrical conductivity [mS m^{-1}]	Velocity [m ns^{-1}]	Attenuation [dB m^{-1}]
Air	1	0	0.3	0
Salt water	80	3000	0.033	600
Fresh water	80	0.5	0.033	0.1
Ice	3-apr	0.01	0.16	0.01
Granite, dry	5	0.01	0.13	0.01
Limestone	4-ago	0.5-2	0.12	0.4-1
Shales	mag-15	1-100	0.09	1-100
Sand, dry	5	0.01	0.13	0.01
Sand, wet	20-30	0.1-1.0	0.06	0.03-0.3
Clay, wet	10	500	0.095	300
Soils:				
Sandy, dry	2.6	1.4	0.19	1
Sandy, wet	25	69	0.06	23
Clayey, dry	2.5	2.7	0.19	3
Clayey, wet	19	500	0.07	200
Frozen	6	0.1	0.12	0.1

Comin et al., 2021

Key choices for root detection with GPR

Antenna Frequency:

- Antenna frequency can range between 10 and 1500 MHz, usually 450 to 1,2 GHz have been used for root detection
- The frequency affects both the depth of investigation and the resolution
- Low frequency antennas (e.g. 450 MHz) can detect roots with diameter larger than 30 mm; high frequency antennas (e.g. 1,2 GHz) can detect roots with diameter larger than 5 mm

Depth [m]	Central Frequency [MHz]
0.5	1000
1.0	500
2.0	200
5.0	100
10.0	50
30.0	25
50.0	10

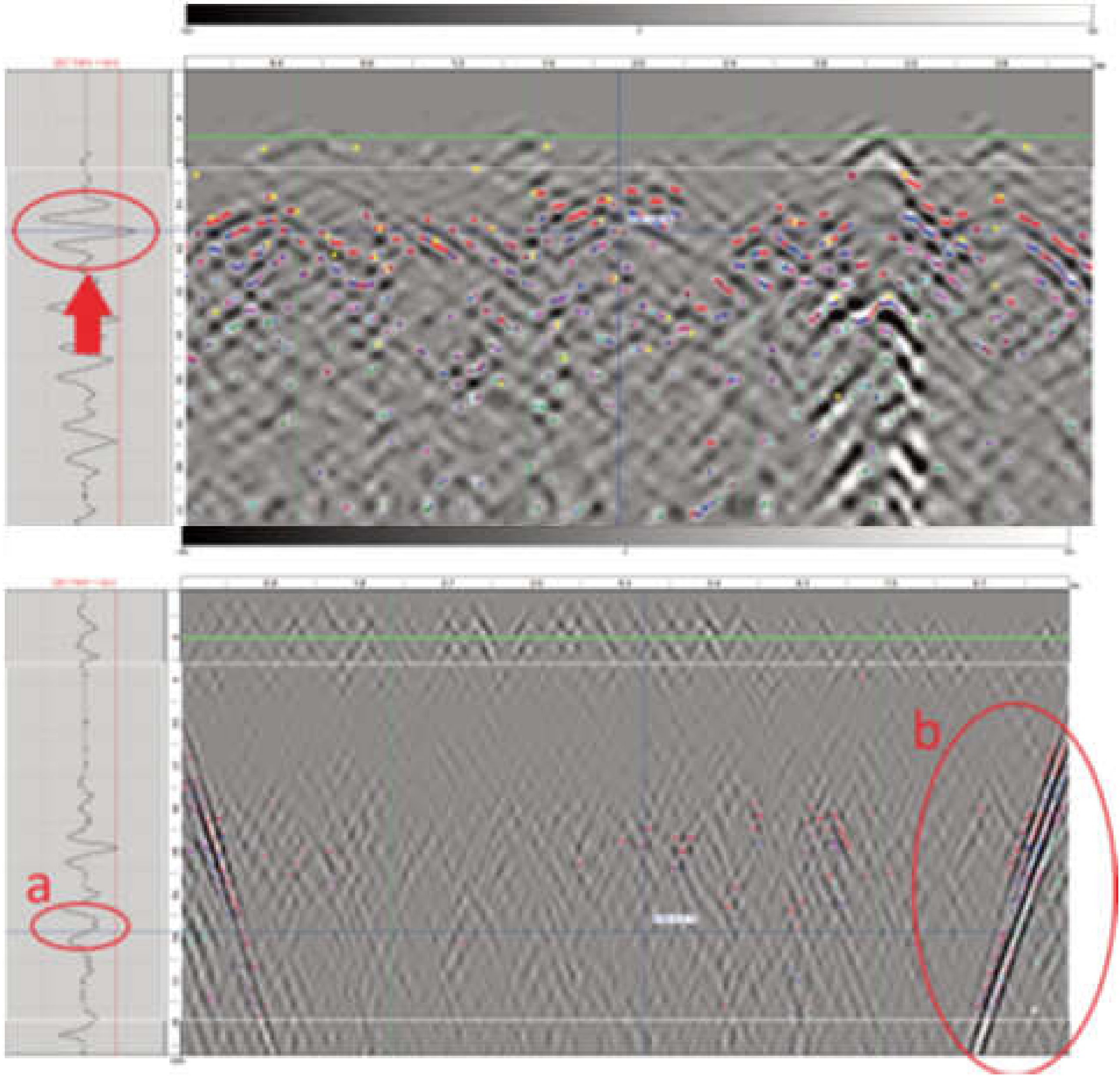
Spatial arrangement:

- Grid
- Circular

Transect spacing: 10-50 cm

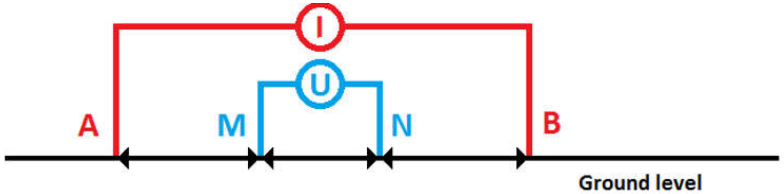
The radargrams:

- Any buried object with different dielectric constant than the media will be displayed as a hyperbola
- Hyperbola are best viewed when the buried object is perpendicular to the direction of scanning; parallel objects are often undetectable
- Non-root objects, such as metal grid or large stones, can produce similar hyperbola as roots, but they can be distinguished by the shape of the signal

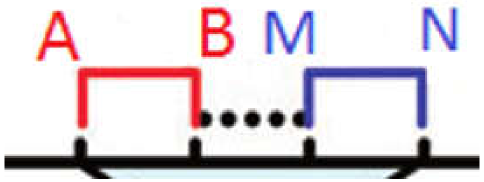


Electric Resistivity Tomography

Wenner configuration



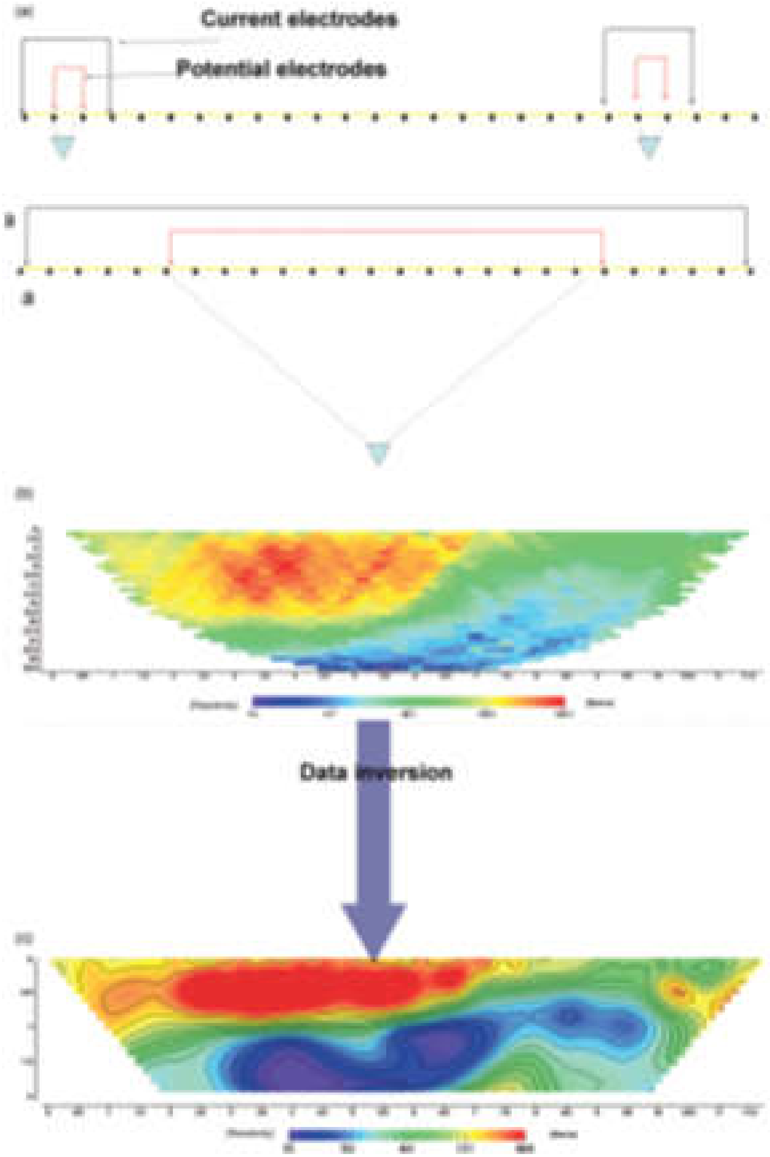
Dipole configuration



Theory

- Injects electric current into the soil and analyses its spatial distribution
- The subsurface distribution of current is affected by the electric resistivity (ohm * m) of the media
- For measuring electric resistivity, at least 4 sensors are required: two for the injection of electric current (conventionally named A and B) and two for the measurement of the difference in electrical potential (M and N).
- Sensors can be arranged according to different configurations
- Resistivity is low in water and high in dry wood.
- High resistivity areas in the soil can be associated to high root density, because of the direct effect of wood on resistivity and because root uptakes depletes soil water.

$$\rho_a = \frac{K\Delta V}{I}$$



Applications and limitations

- **Mostly used for detecting coarse root biomass**

Only woody roots cause a resistive response, making absorbing roots undetectable (directly)

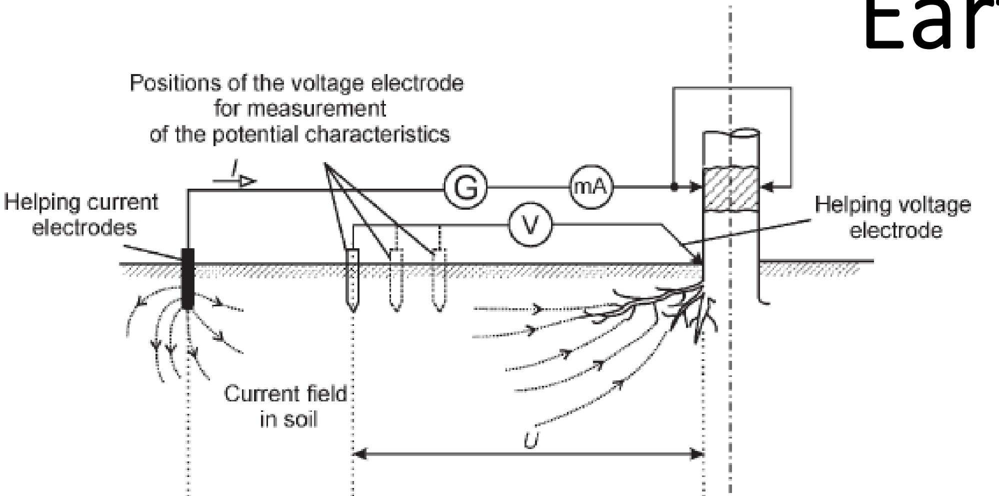
- **Works well in moist soils and in medium to fine soil textures**

Excessively dry soils or sandy soils can be highly resistive and mask root signal

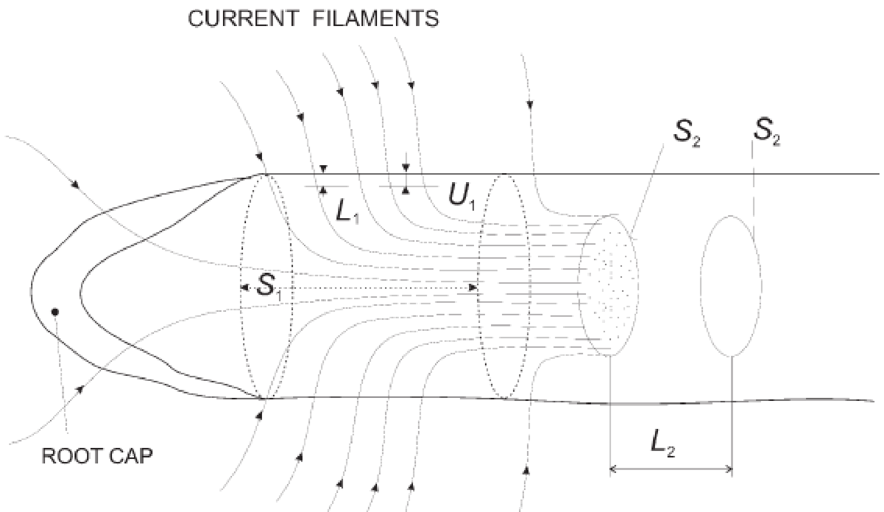
- **Electrodes must be placed in the soil**

Cannot be used in paved soil unless the pavement is removed

Earth Impedance Method



Cermak et al., 2006



Aubrecht et al., 2006

Theory

- Fine roots are the main below-ground site of exchange between the plant and the soil
- Following soil electricity enforcement, the electricity flows along the same path as soil water
- If a plant root is submerged in an aqueous solution and connected to an electric circuit, the electric current will flow to the plant through the electrically conducting (ion absorbing) root surfaces

Method to detect fine roots

$$A_{root} = \rho l \frac{I}{U}$$

ρ is resistivity
L is distance stem to electrode
I is the current flow
U is the difference in potential

Earth Impedance Method

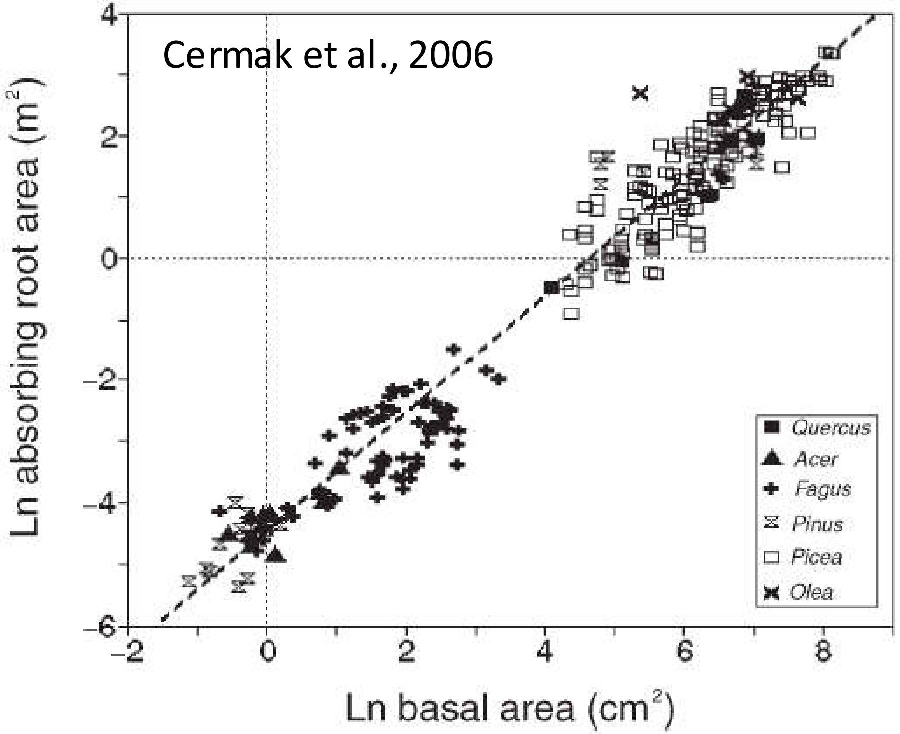


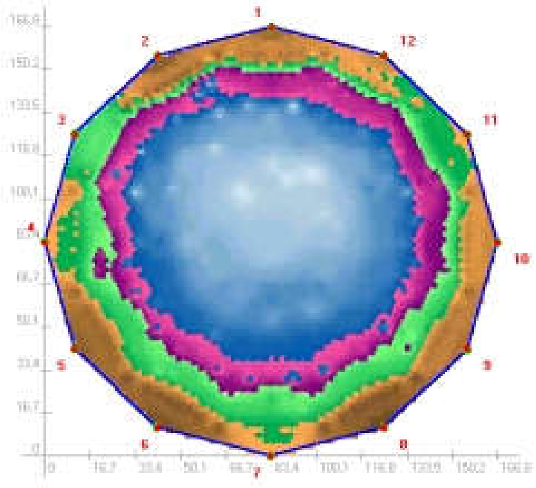
Figure 6. Relationship between root absorbing surface and basal area in six coniferous and broadleaf species (altogether 350 trees) differing in tree size (stem diameter ranging from about 0.5 to 55 cm): $\log(A_{root}) = 0.88\log(A_{bas}) - 2$, $r^2 = 0.90$ (statistically significant at $P < 0.001$) and SE = 0.33.

Applications and limitations

- The only indirect method to quantify absorbing root area
- Not really validated, but scaled well with trunk basal area
- Cannot be used in paved soils without removing the pavement

Sonic tomography

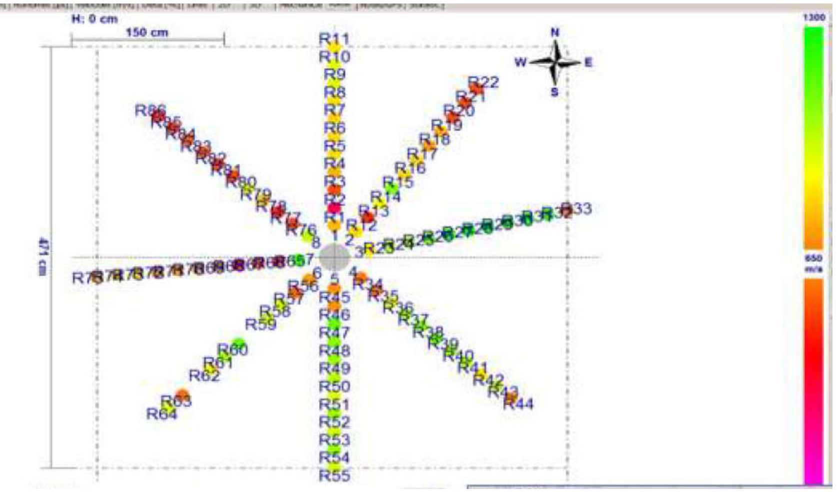
Theory



- ST is applied to detect trunk decay, because sound moves faster in healthy than in decayed wood.
- In soil, sound travels between 250-400 m/s (Rinn, 2016)
- In roots, sound is reported to travel at 500 to 4000 m/s (Divos et al., 2009; Proto et al., 2020)
- The travel time of the sound wave decreases significantly when the source of sound and the receiver are physically connected by a root compared to when the wave travels through unrooted soil (Bulza and Goncz, 2015)

Sonic tomography

Applications and limitations



Red: slower sound speed, lower root density

Orange: medium sound speed, medium root density

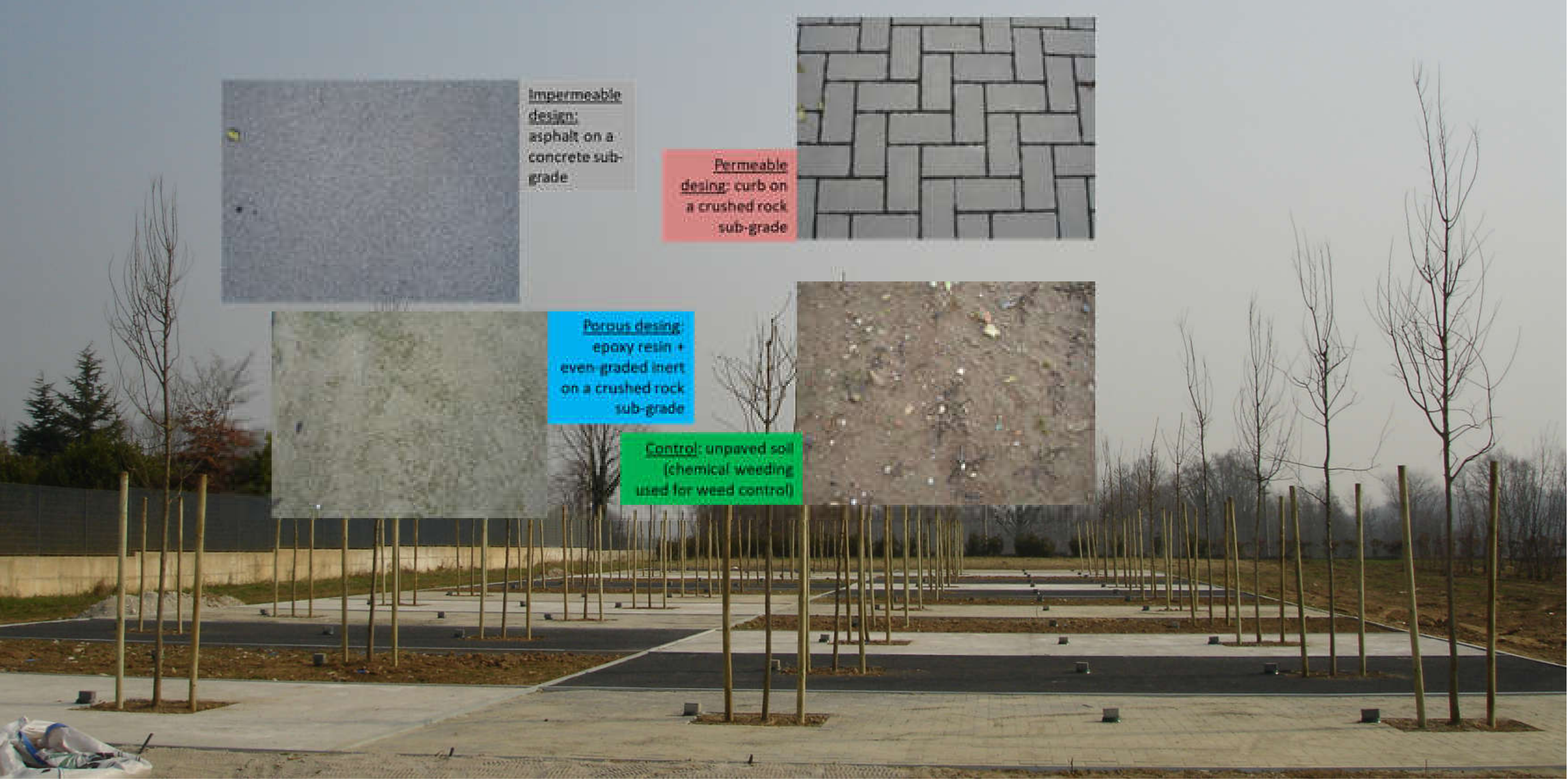
Green: higher sound speed, high root density

- Two main methods have been proposed:

1. In ArboradixTM the sound moves inward, from the tapping point in the soil to the trunk;
2. In ArborSonic3D® the sound moves outward, from the tapped trunk to the receivers placed in the soil.

- More effective to determine root density than the size of individual roots (Proto et al., 2020)
- The minimum diameter detected from the root sonic tomography is approximately 3-4 cm (Buza and Goncz, 2015; Divos et al. 2009; Rinn, 2016)
- **Can discriminate overlapping roots of neighboring trees**
- **Can be used in paved soil without damaging the pavement**
- More knowledge is needed, however, about the influence of soil compaction, soil cover materials, and moisture on sound speed (Rinn, 2016)

In March 2012, 48 *Fraxinus ornus* and *Celtis australis* trees were planted in soils covered by different types of pavement



In Fall 2020, tree roots were investigated using different methods, with the aims to:

1- Identify reliable indirect root detection method that can be applied to paved urban sites

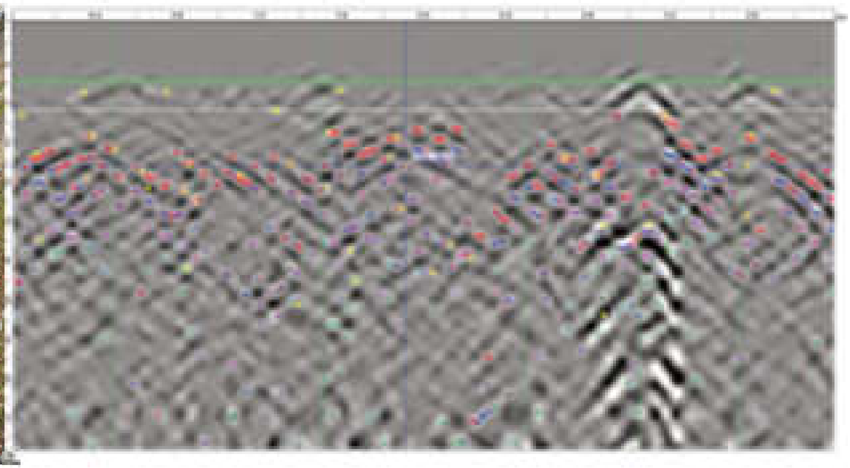
2- Evaluate the effect of pavements on root detection

3- Apply root detection methods for understanding the effect of pavements on roots

Root detection – non invasive

1 – Ground Penetrating Radar (in cooperation with Studio Planta):

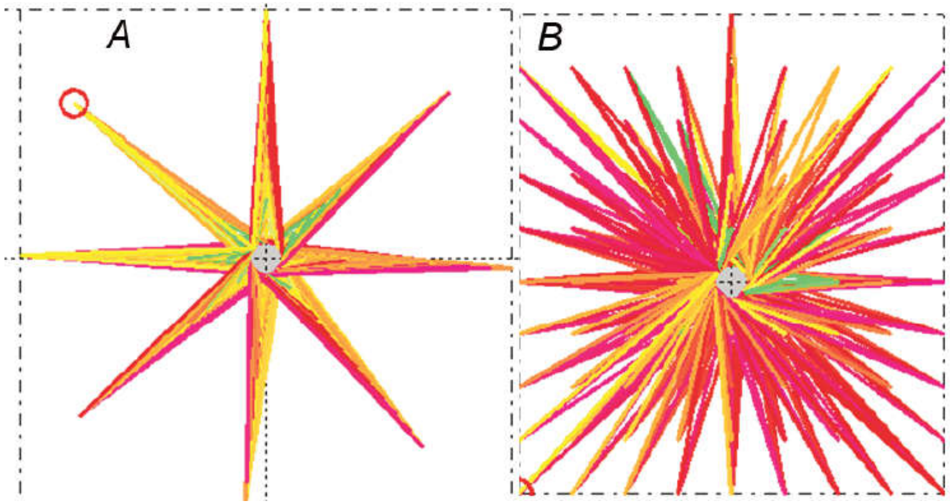
- Tree Radar GPR system (TRU™ Model, Tree Radar Inc., Silver Spring, MA, USA) equipped with a portable TerraSIRch Subsurface Interface Radar system (SIR-3000, GSSI, Salem, NH) and a 900 MHz antenna
- Twenty cm pitch concentric virtual trenches were scanned
- Three soil horizons were investigated (0-30 cm; 30-60 cm; 60-90 cm)
- TreeWin TBA (V3.8.1) was used to generate the root morphology maps (Bassuk et al., 2011)



Root detection – non invasive

2 – Sonic Tomography (In cooperation with Dendrotec):

- ArboradixTM was used on 16 trees
- Measurements were done before and after removing the pavements
- Measurements were conducted using two arrangements: the star arrangement (A) did not provide enough spatial information and was replaced by a radial arrangement (B)



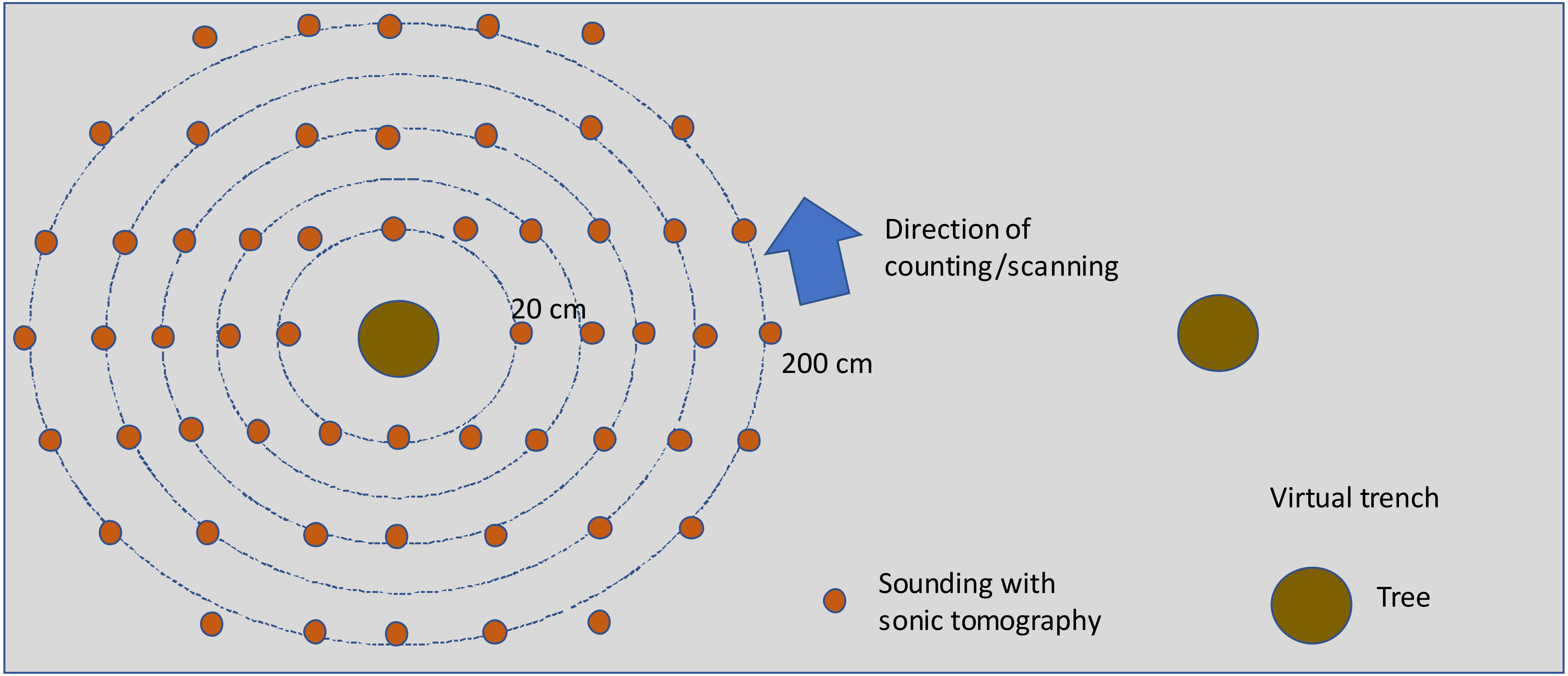
Root detection – validation

3 – Suction excavator, AirpadeTM, and manual count

- Pavements were removed, and roots exposed using soft-dig techniques down to 30 cm below grade
- Roots with diameter larger than 1 cm were manually counted along twenty cm pitch concentric transects
- 4 individual roots per tree were cut at the flare and their length and diameter at the attachment were measured. Then, fine to coarse roots separated and weighed (FW and DW)



Root detection – validation

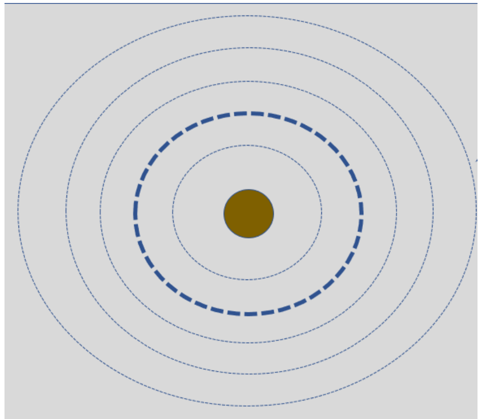



RESULTS

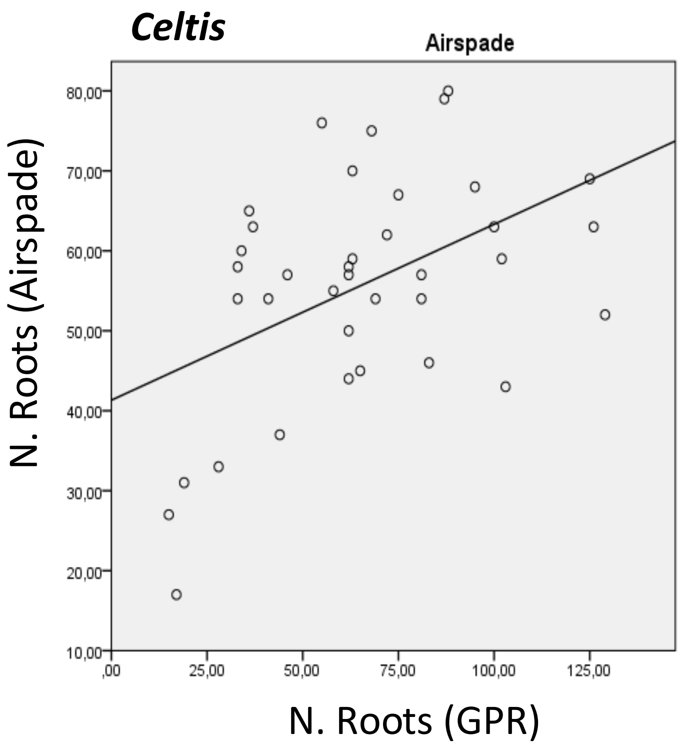
Total root number per trench: Manual count vs. GPR

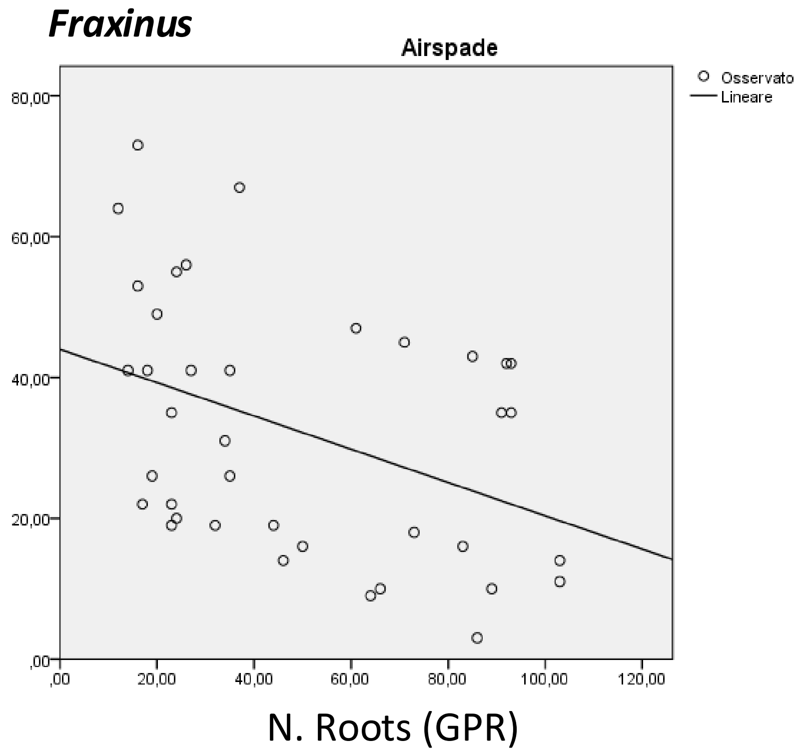
- The number of roots with D>1cm were counted manually in each of the 20 cm circular transects at a distance from the flare from 20 cm to 200 cm
- GPR depth was constrained to allow comparable measurements with manual count
- Root count by GPR was fitted to manual root count

P > 0,05

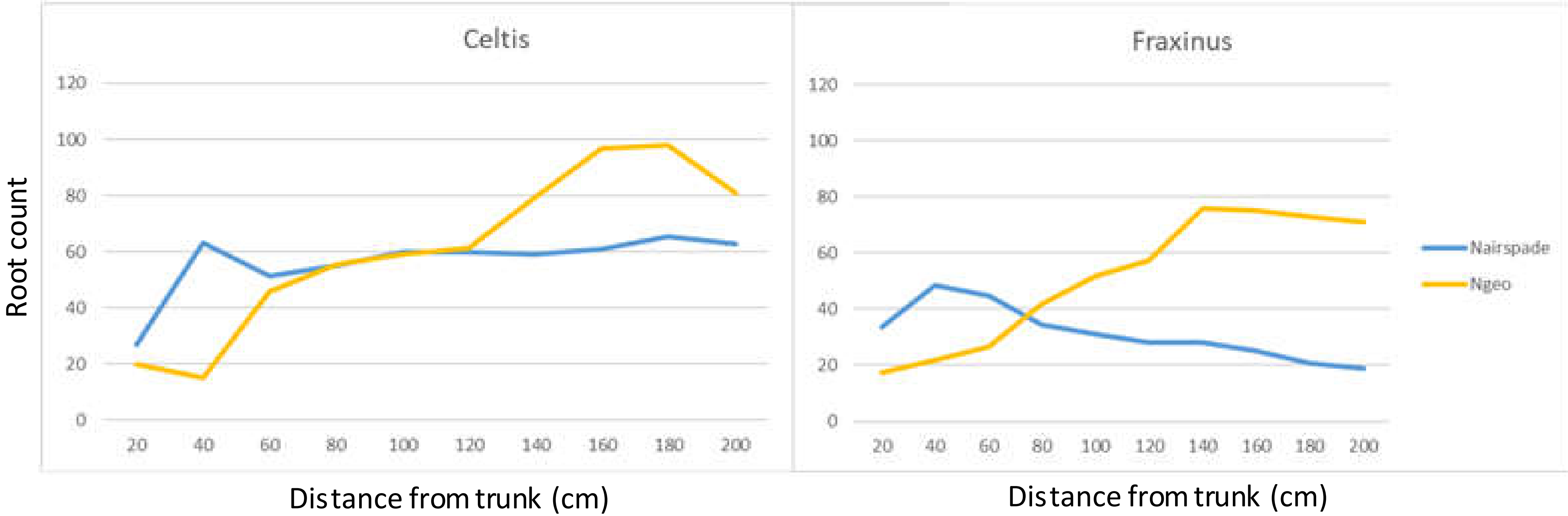


GPR and manual root count were not consistent for root number, particularly in ash





Root number per distance: Manual count vs. GPR

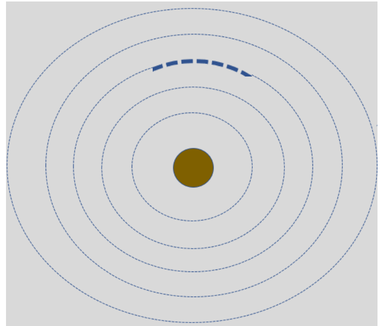


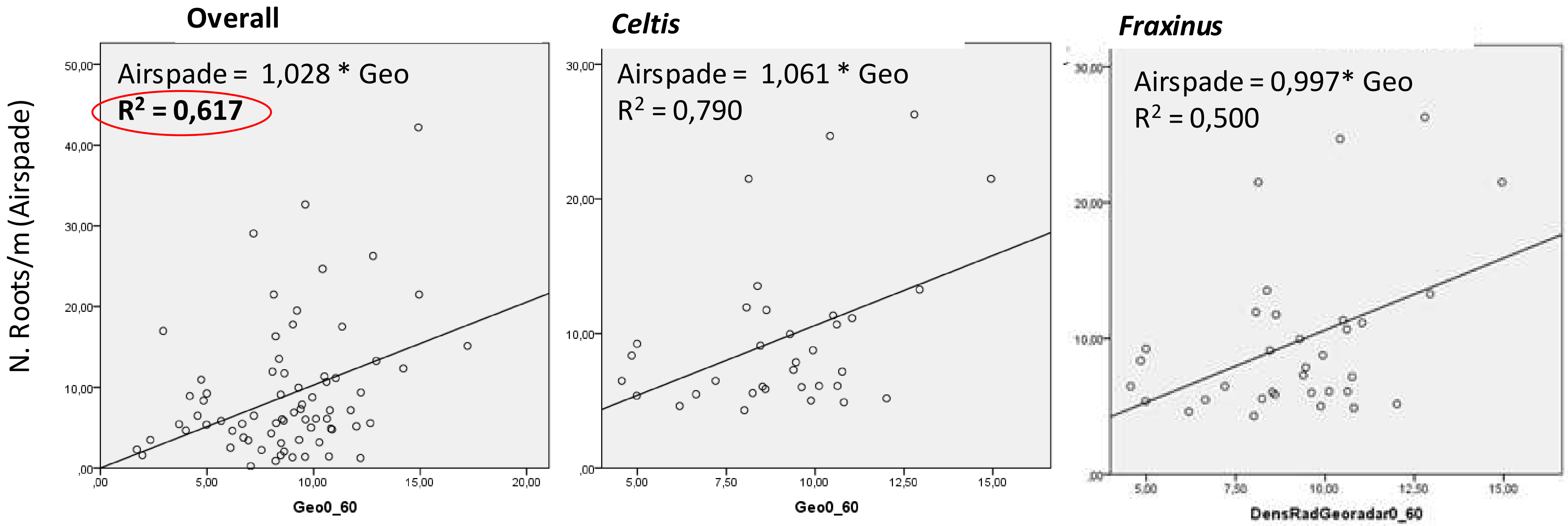
- GPR underestimated root number near the trunk (roots very close to each other, short trench circumference, overlapping roots from the same tree?)

- GPR overestimated root number far from the trunk (roots smaller in diameter, longer trench circumference, increased detection of non-root object, overlapping root from neighboring trees?)

Root linear density: Manual count vs. GPR

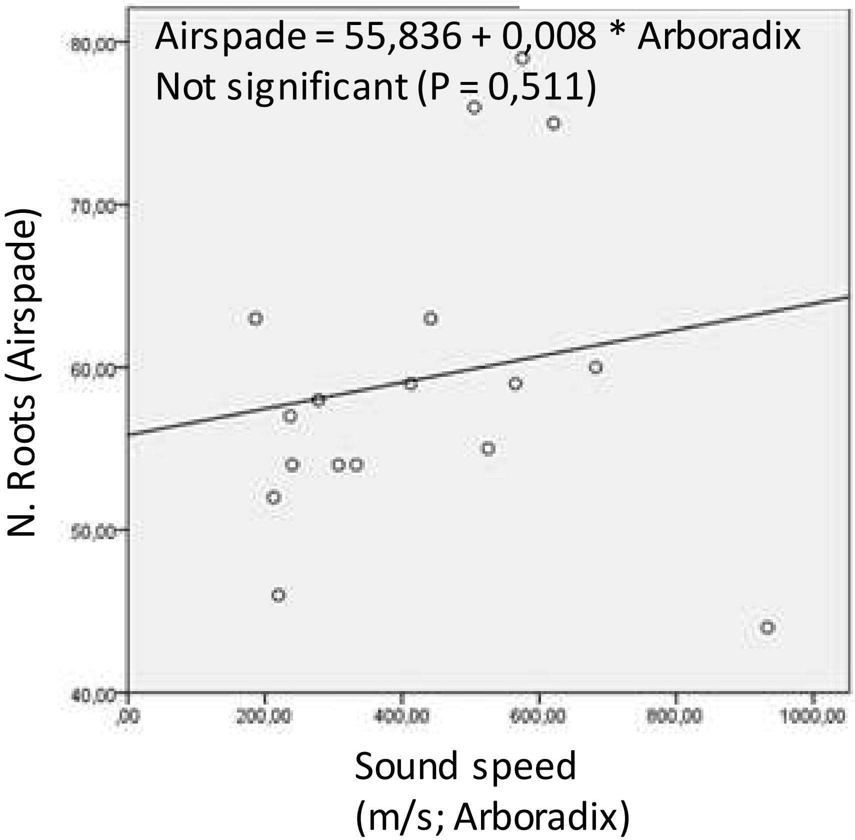
- It is calculated as total root count over the circumference of the trench
- The number of roots per m trench yields much better correlations between the two methods
- Root detected by GPR at 0-60 cm correlated better than those detected at 0-30 cm with manual count



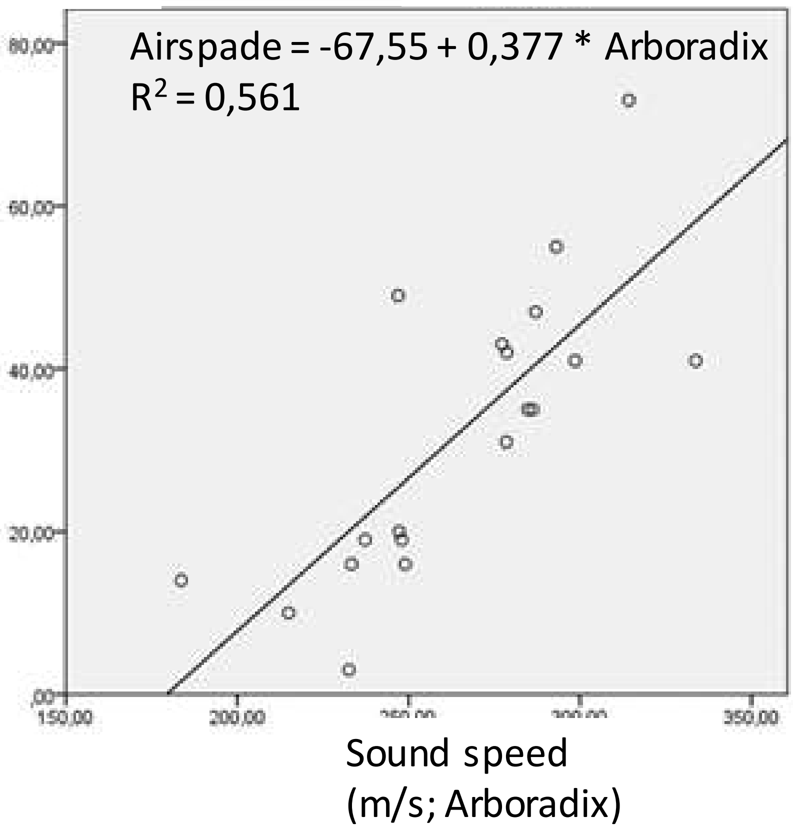


Arboradix Vs. Manual count

Celtis



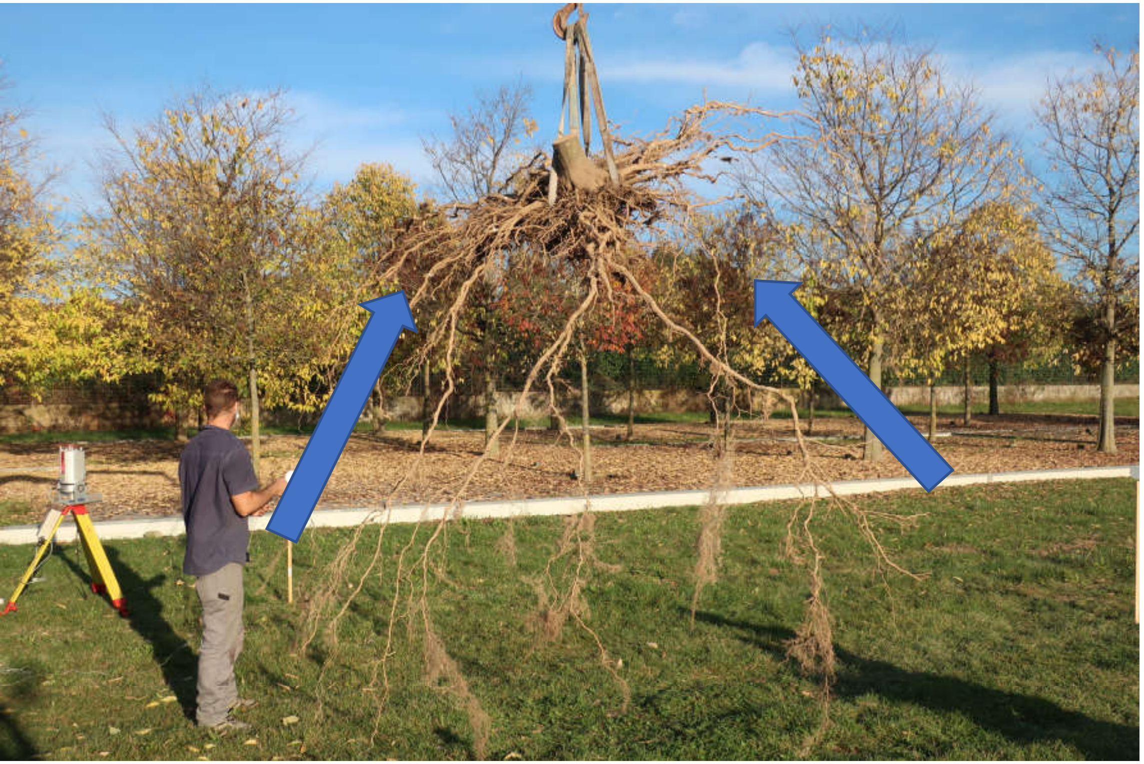
Fraxinus



In *Fraxinus*, better correlations were found between sound speed and total root number (R2 = 0,561) than between sound speed and root n. per meter scan (R2 = 0,439)

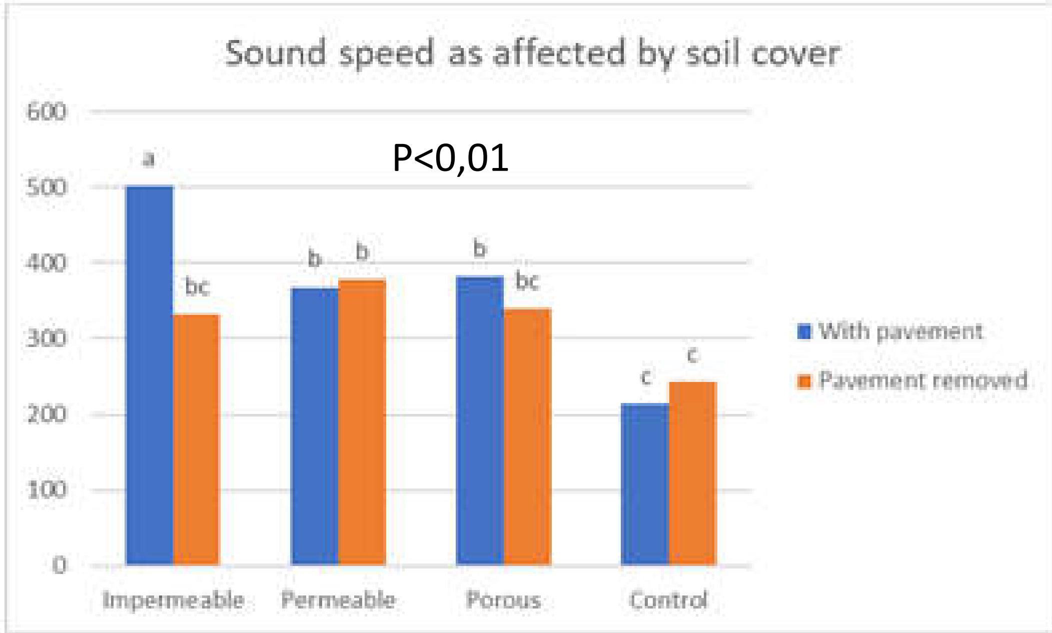
Arboradix Vs. Manual count

Well-spaced, straightforward roots (*Fraxinus*) yielded much better Arboradix estimates than densely packed roots with some circling (*Celtis*)

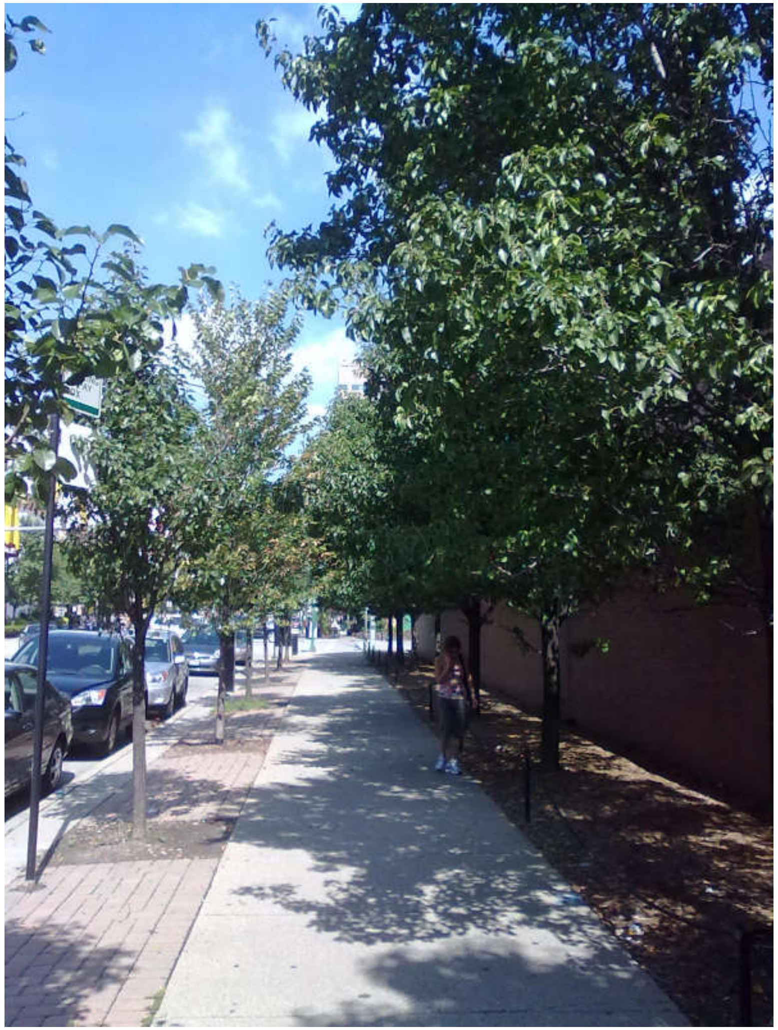


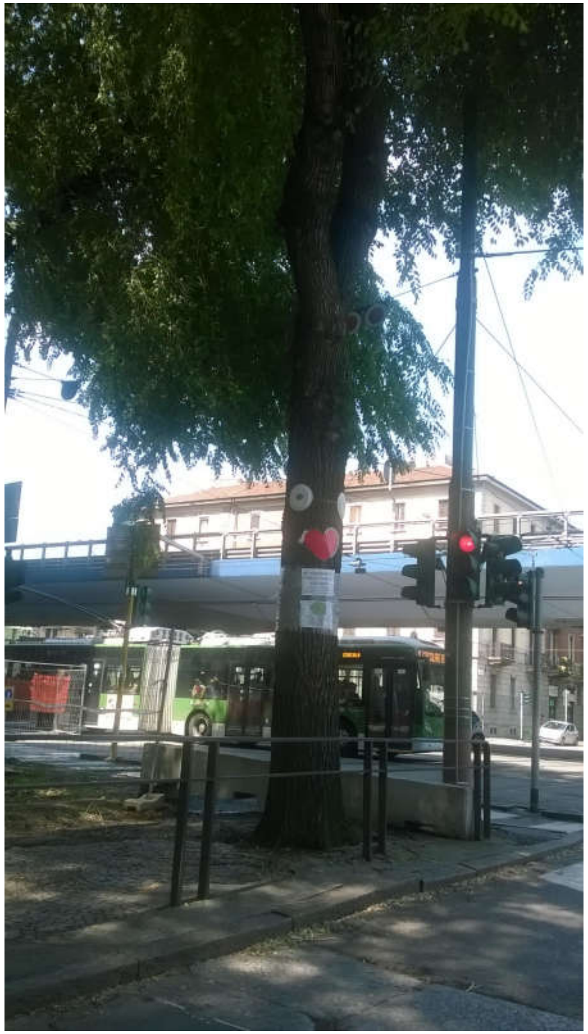
Arboradix – pavement matters

- Sound speed ranged between 210 m/s to 490 m/s
- Pavements with a concrete subgrade affect sound speed to a larger extent than pavements with a crushed rock subgrade



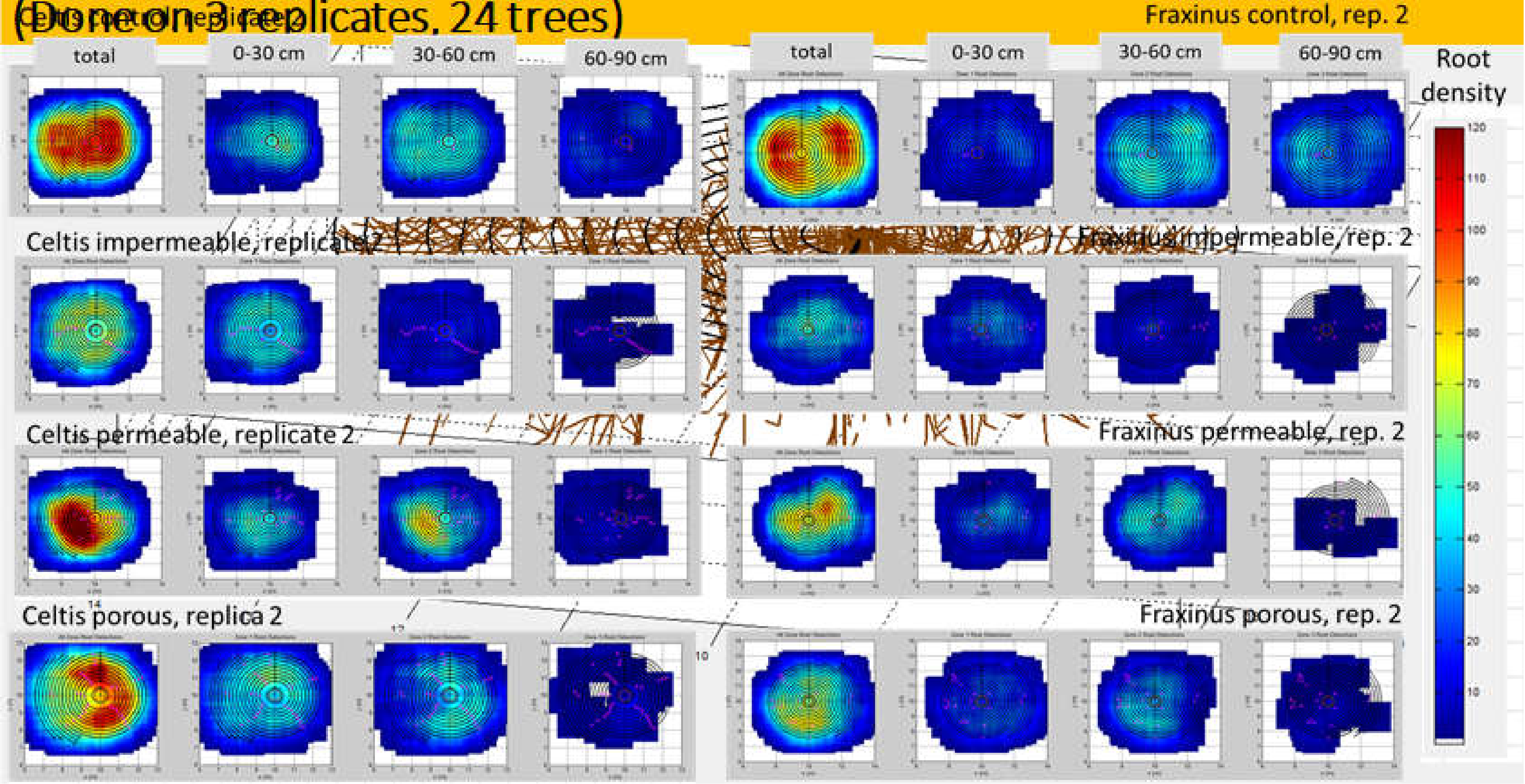
Arboradix – pavement matters

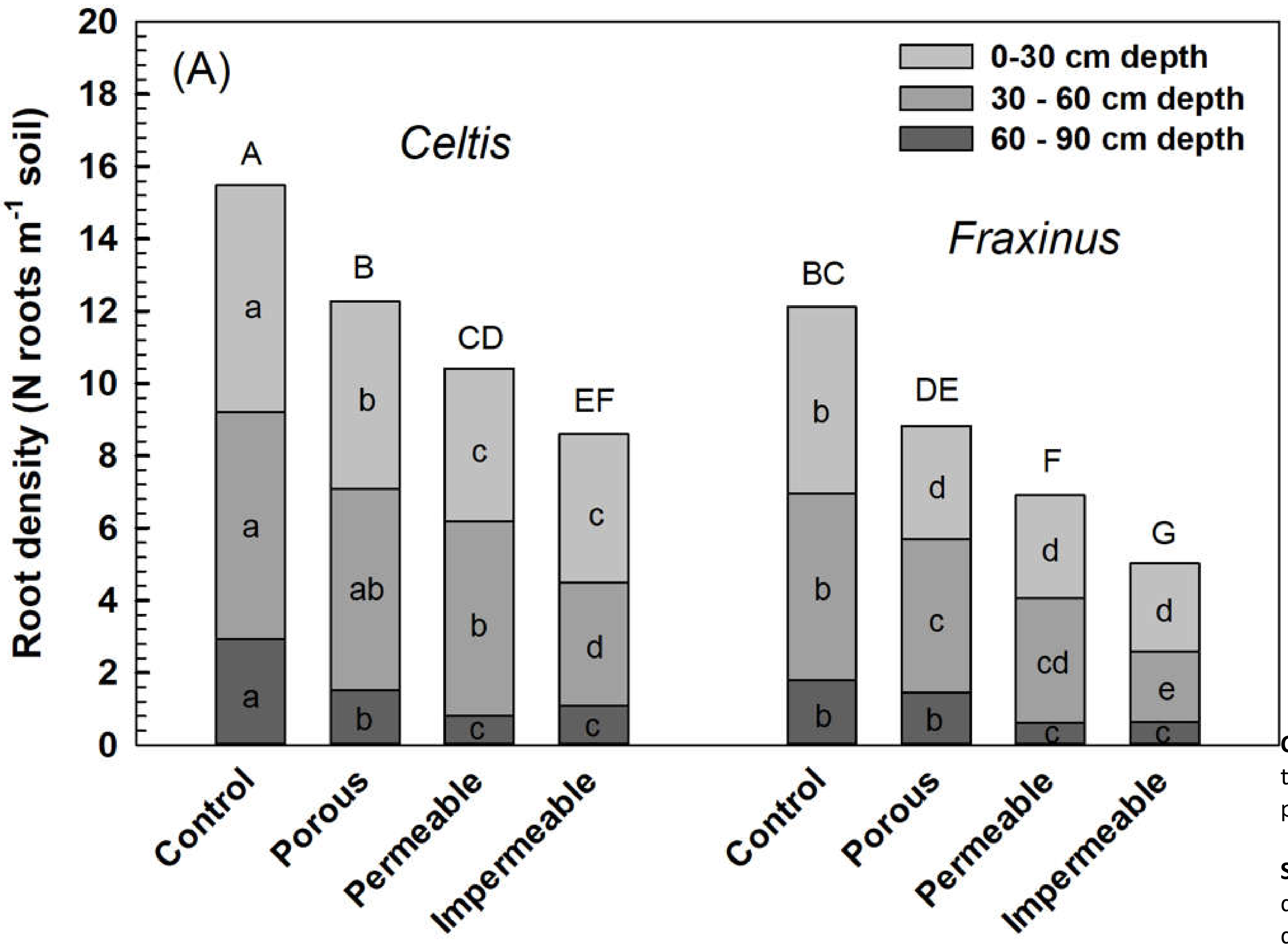




Take care when investigating root system of trees paved with different materials

GPR was used to assess the effects of pavements on root density (Done on 3 replicates, 24 trees)



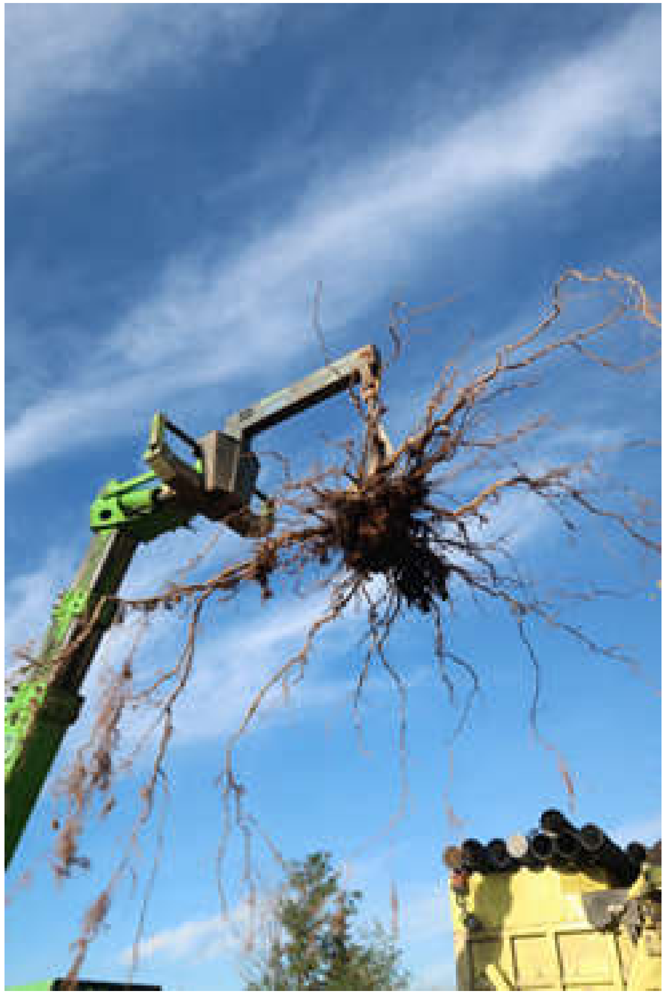


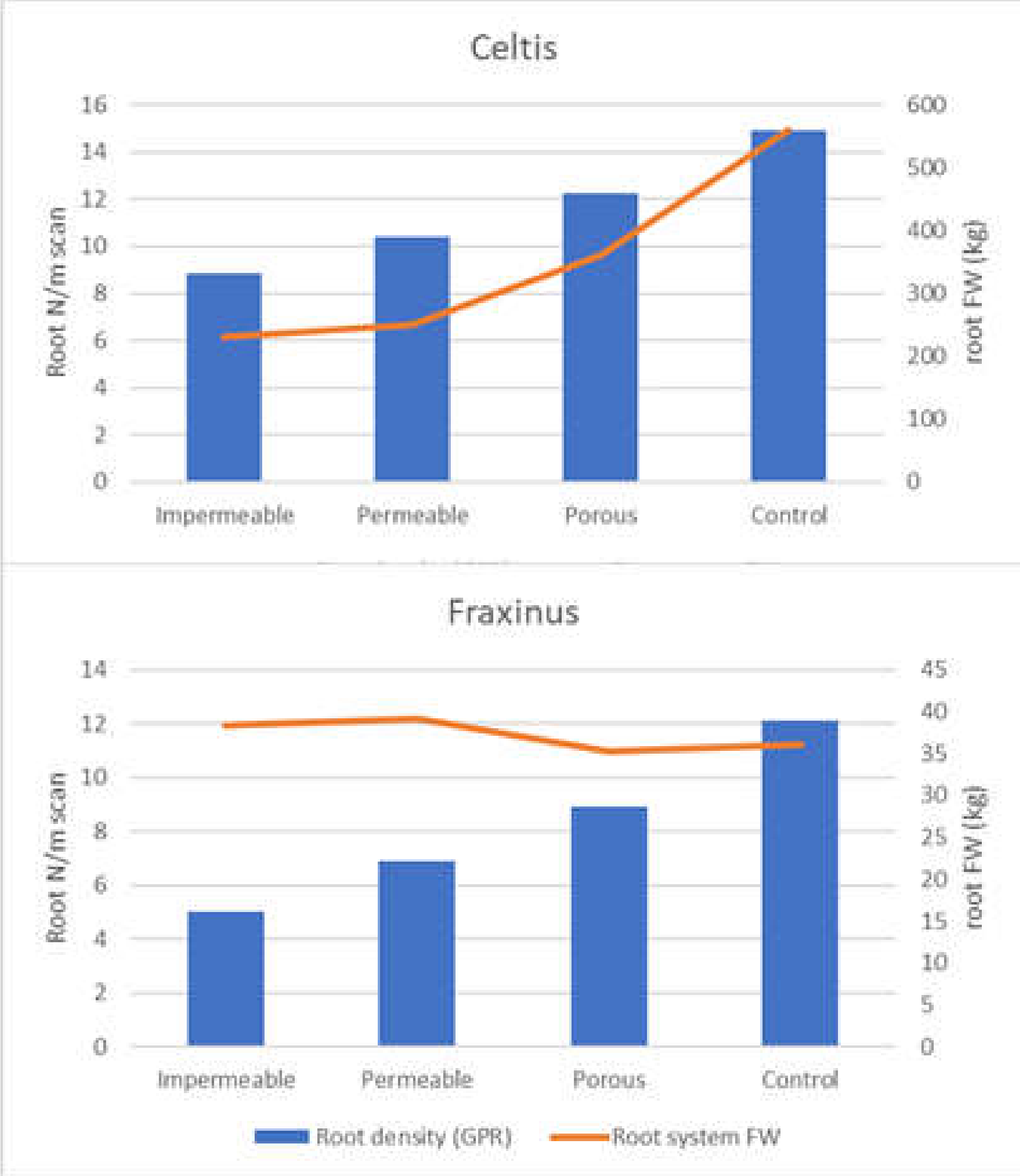
- Eighty-five to **92% of roots** were located in the **uppermost 60 cm** of soil;
- **Impermeable pavements increased** the fraction of **roots located in the uppermost 30 cm** below grade (47.7%) compared to other treatments (40.6%);
- **control trees had more deep roots** (> 60 cm below grade, 17.3%) compared to porous (14.4%), impermeable (12.7%) treatments, and permeable pavements (8.4%).

Capital letters indicate differences in total root density among species and pavement treatments at p<0,01

Small letters indicate significant differences in root density within a depth range among species and pavement treatments at p<0,01

Root system fresh weight





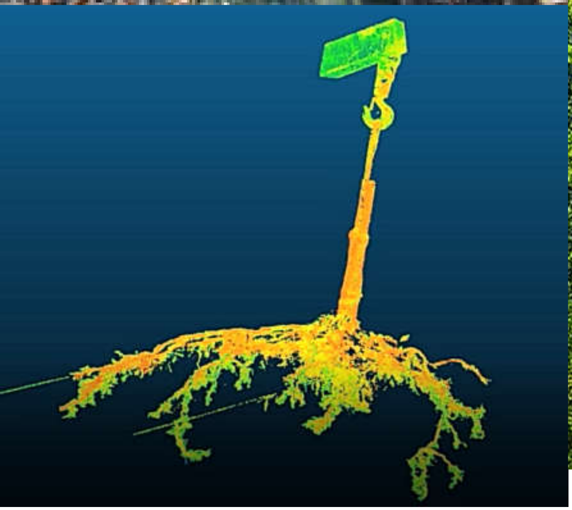
Similar root number can yield different biomass

Difficult make inter-specific comparison in root biomass

Conclusions

- Non-invasive methods can provide some approximation about root system characteristics, but the information collected is far from being conclusive
- Pavements affected both methods for root detection
- Pavements had a significant effect on root morphology in the two species, although no evidence was found that pavements depress tree health (see webinar TREEFUND 16 Nov. 2021)

Future perspectives
(In cooperation with INRA Montpellier, France)

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