Belowground analysis of tree root systems in temperate tree-based intercropping with the use of ground penetrating radar

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Introduction

Despite strong evidence of long-term ecological benefits of integrating trees into agricultural systems, agroforestry remains an under-explored approach to agriculture in southern Ontario, Canada (Thevathasan & Gordon 2004). In tree-based intercropping systems (fig.1), understanding root distribution and belowground biomass allocation patterns is not only important for minimization of interspecific competition, but also for estimation of biomass for improved calculations of carbon storage. However, the study of root dynamics *in situ* typically requires destructive sampling and to date is poorly understood.

Accordingly, this study investigates tree root structure interpreted from subsurface geo-images generated from non-destructive ground penetrating radar (GPR).

Figure 1. Agroforestry Research Station in Guelph, Ontario, Canada was established in 1987 as a tree intercropping experiment site with ten tree species including poplar hybrid (*Populus spp.*) (A) and white cedar (*Thuja occidentalis*) (B), intercropped with rotational corn (*Zea mays*) (A & B) , soybean (*Glycine max*), wheat (*Tritium aestivum*) or barely (*Hordeum vulgare*).

The use of GPR to detect tree roots

The GPR unit (fig. 2) emits electromagnetic (EM) pulses into the ground at a known distance interval. EM waves are reflected at subsurface interfaces with a difference in dielectric permittivity, such as the soil-root interface of coarse roots. The amplitude and travel time of the reflected EM signals are recorded by the GPR's receiving antenna. Sequential EM scans are combined into a cross-sectional image of the subsurface (fig. 3 & fig. 7A). Evidence supports a correlation between reflected waveform parameters and tree root diameter (Barton & Montagu 2004; Butnor et al. 2003; Hirano et al. 2012).

Figure 2. Collecting subsurface data using a 1000 MHz GPR in a tree-based intercropping system.

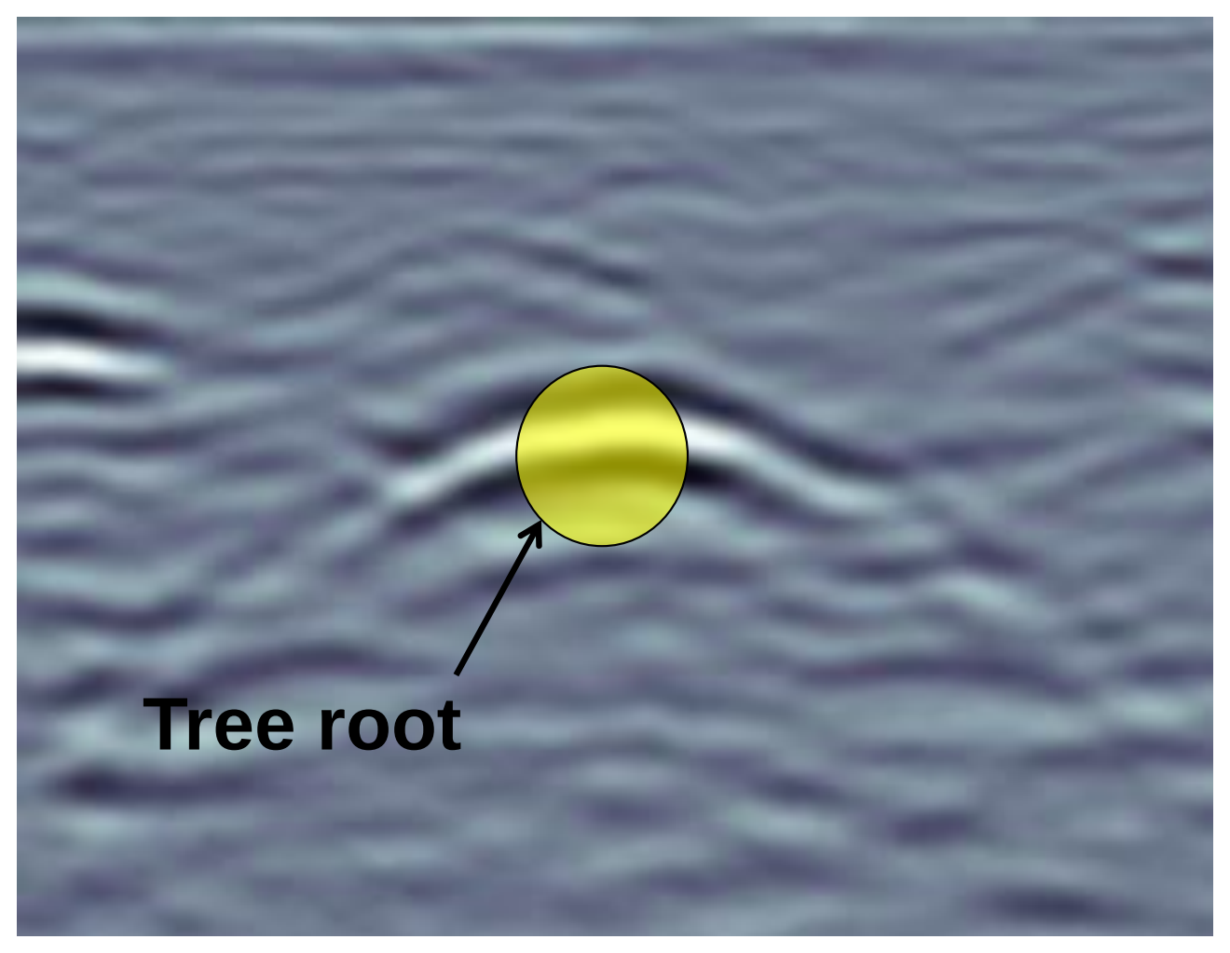

Figure 3. Geo-image showing hyperbolic signal reflection at root-soil interface where a root is orientated roughly perpendicular to the geo-image plane.

Soil considerations

Understanding the limitations of GPR is important when deciding if the site is applicable for GPR study and also later during data interpretation. The greater the dielectric constant of a material, the more the radar signal is attenuated and dissipates as heat resulting in reduced radar penetration depth (Daniels 1996). Higher clay, moisture and salt content in the soil will increase signal attenuation. Dry and sandy soils are optimal. The research site we collected our data has sandy loam soils. Higher frequency radar (e.g. 900 to 1500 MHz) results in greater resolution than a lower frequency (e.g. 100 to 500 MHz), but penetration depth is reduced (Daniels 1996). We used a 1000 MHz system (fig. 2) that optimized visualization needs for high resolution of tree root locations with a penetration depth needed to capture most of the belowground biomass.

Methodology

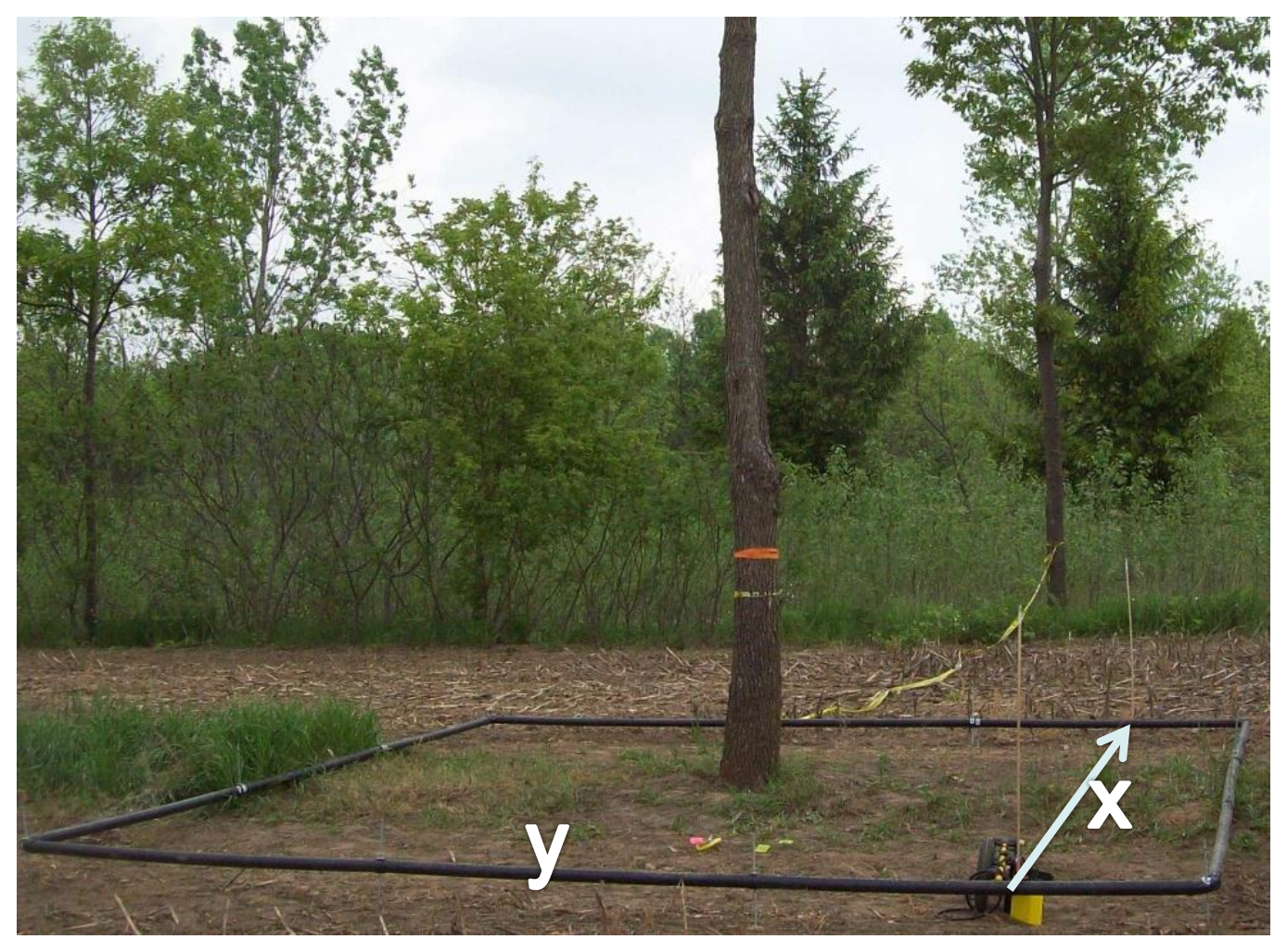

Figure 4. 4.5 × 4.5m grid frame surrounding black walnut with guide-line – shown by white arrow – to collect GPR transects of 10cm spacing in the x and y directions.

Figure 5. Excavation and tree root sampling of Norway spruce.

Using a 1000 MHz GPR system, we first determined the signal velocity – derived from signal reflection travel time – of the EM pulses by scanning across the area where a metal rod is in the subsurface at known depth. We then collected GPR data surrounding 3 replicates of 5 tree species – poplar hybrid (*Populus spp.*), black walnut (*Juglans nigra*), Norway spruce (*Picea abies*), red oak (*Quercus rubra*) and white cedar (*Thuja occidentalis*) – within 4.5×4.5m plots with grid transect lines at 10cm intervals in the x and y directions (fig. 4). Subsequently, root reflections were visually identified on the produced geo-images to measure frequency of root presence 3-dimentionally (fig. 8). During complete excavations of the tree root systems (fig. 5), 1x1m soil profile segments were compared to geo-images to determine accuracy (fig. 7).

Preliminary results

Geo-images were compared to excavated soil profiles (fig. 7) and hyperbolic reflections were confirmed to locate coarse tree roots with an accuracy of >45%. Accuracy increases to >80% when locating only larger roots of diameter ≥1.0cm. Methodological limitations include closely clustered roots that appear as one reflection in the geo-image as well as severe signal attenuation that occurs below approximately 0.7m. It should be noted there is a moraine layer less than a metre below the surface and very few coarse roots are present at this depth. Although a tendency has been observed between reflection pattern parameters and root diameter, a predicted relationship will require further GPR data analysis.

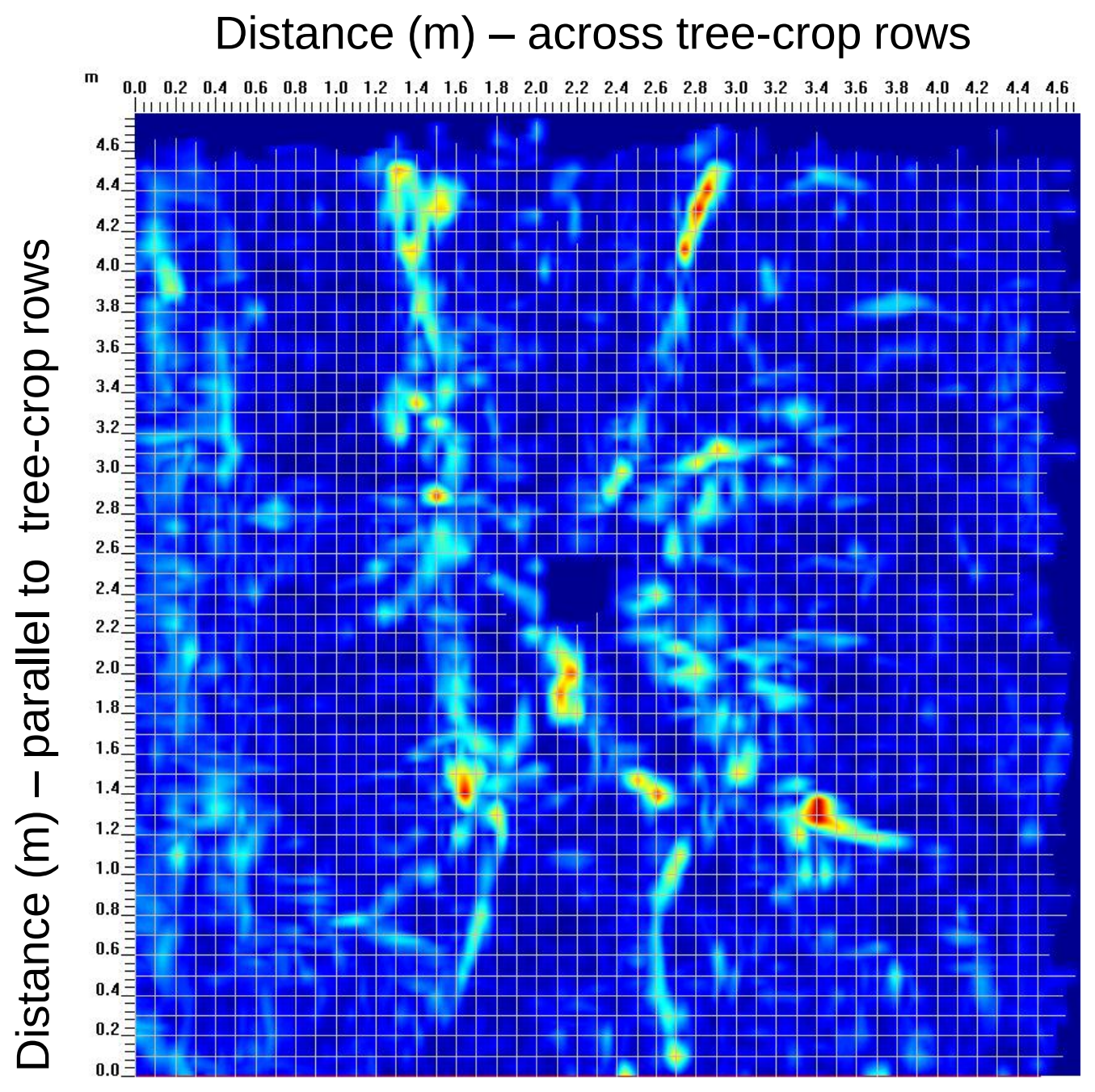

Figure 6. Interpolated GPR signal reflection amplitudes at depth 30 to 32.5cm of a spruce tree. Tree stem located at centre of plot. Amplitude gradient represented high to low as red to dark blue. Signal velocity was 0.090m·ns^{-1}.

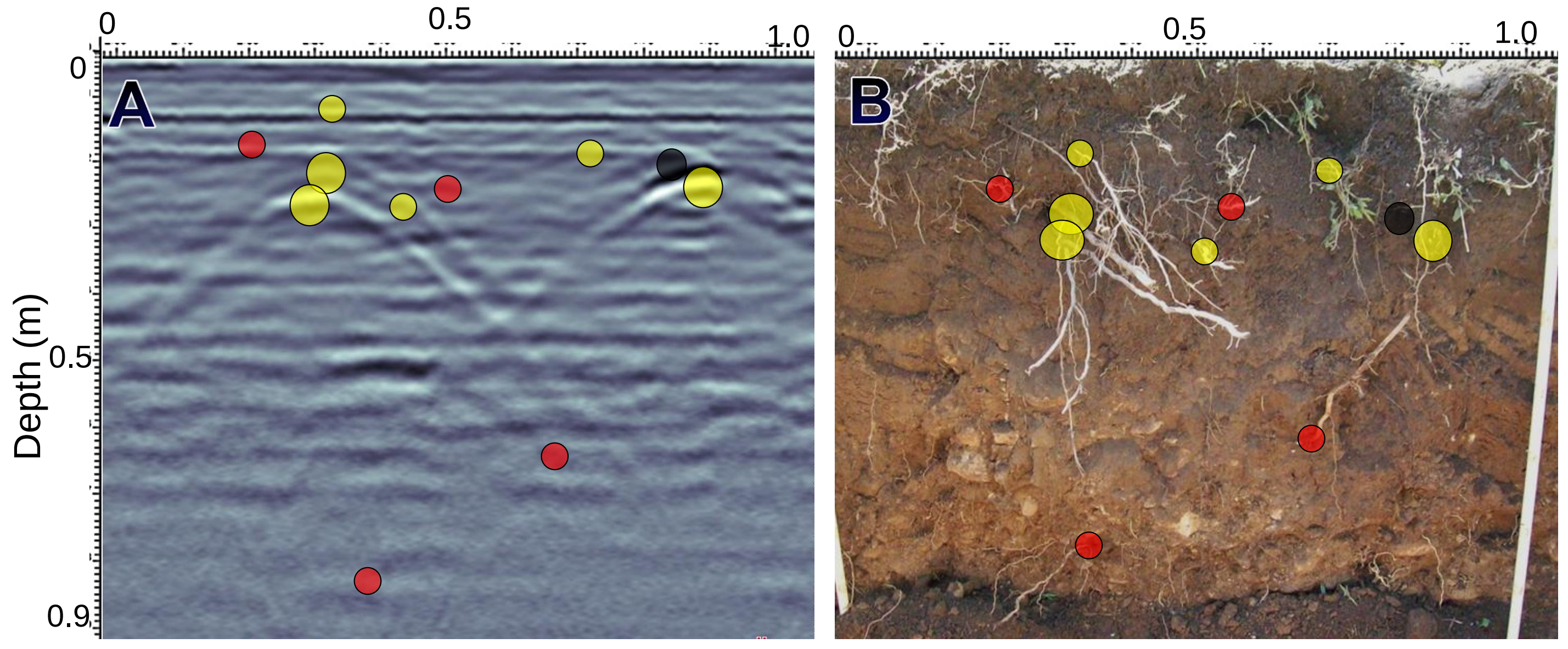

Figure 7. 1x1m cross-sectional subsurface geo-image (A) corresponding to excavated soil profile (B) 2m from poplar stem. Reflection patterns of tree roots and corresponding identified root location in soil profile are shown in yellow, false identification of a root in black and unidentified roots in red. Small circles represent roots of diameter ≥0.2cm and large circles represent roots ≥1.0cm. Signal velocity in the subsurface was approximately 0.08m·ns^{-1}.

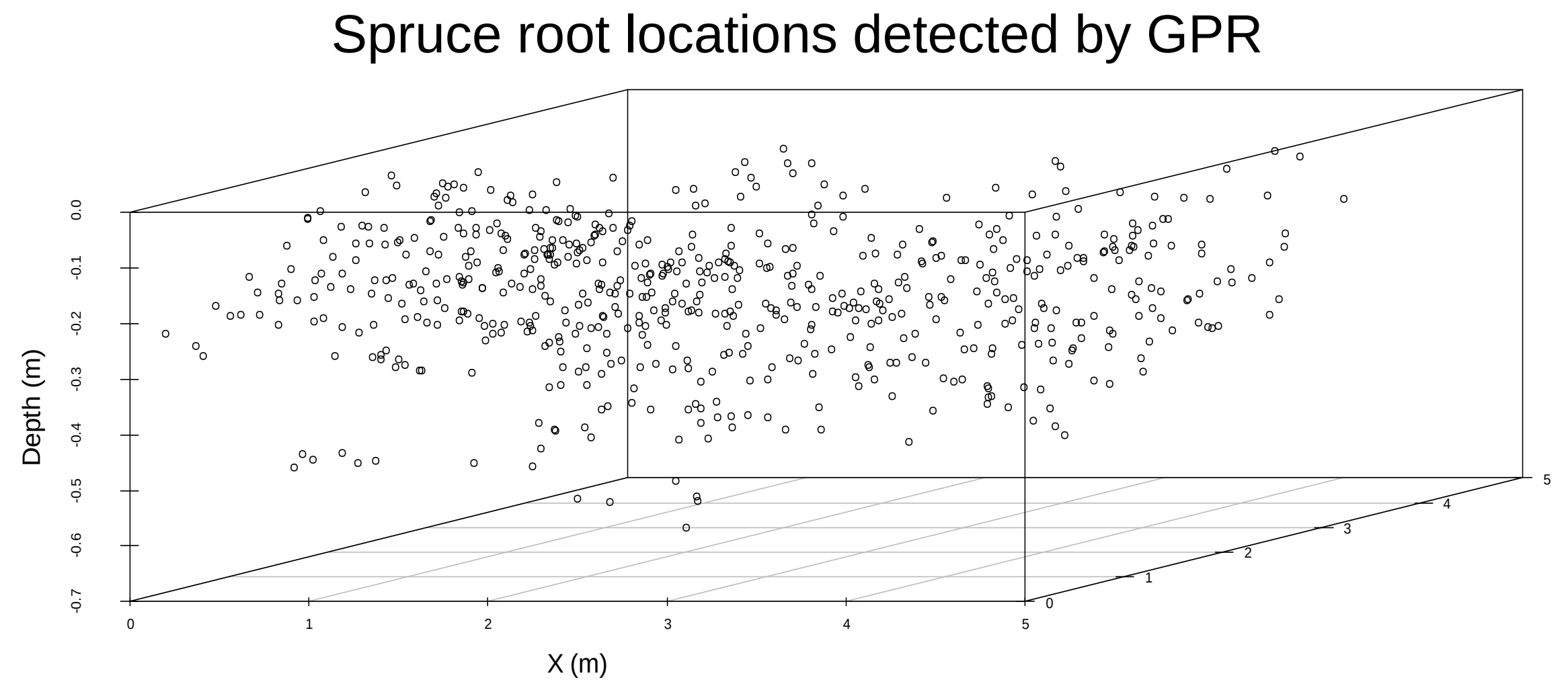

Figure 8. 3-dimensional point pattern representing detected coarse root locations of Norway spruce. Tree root reflection patterns were identified along 92 collected GPR geo-images orientated in x and y directions. Tree stem located approximately at the centre of the plot.

Frequency distribution data in 10cm increments in the profile (fig. 9) indicates variance between tree species. Apparent trends included oak and walnut displaying more dispersed rooting with depth than poplar or spruce whose roots appear concentrated above 30cm.

Exploratory spatial analysis has also indicated variation in directionality. Therefore, the tree roots may be clustered differently below the tree row or crop rows. This requires further analysis.

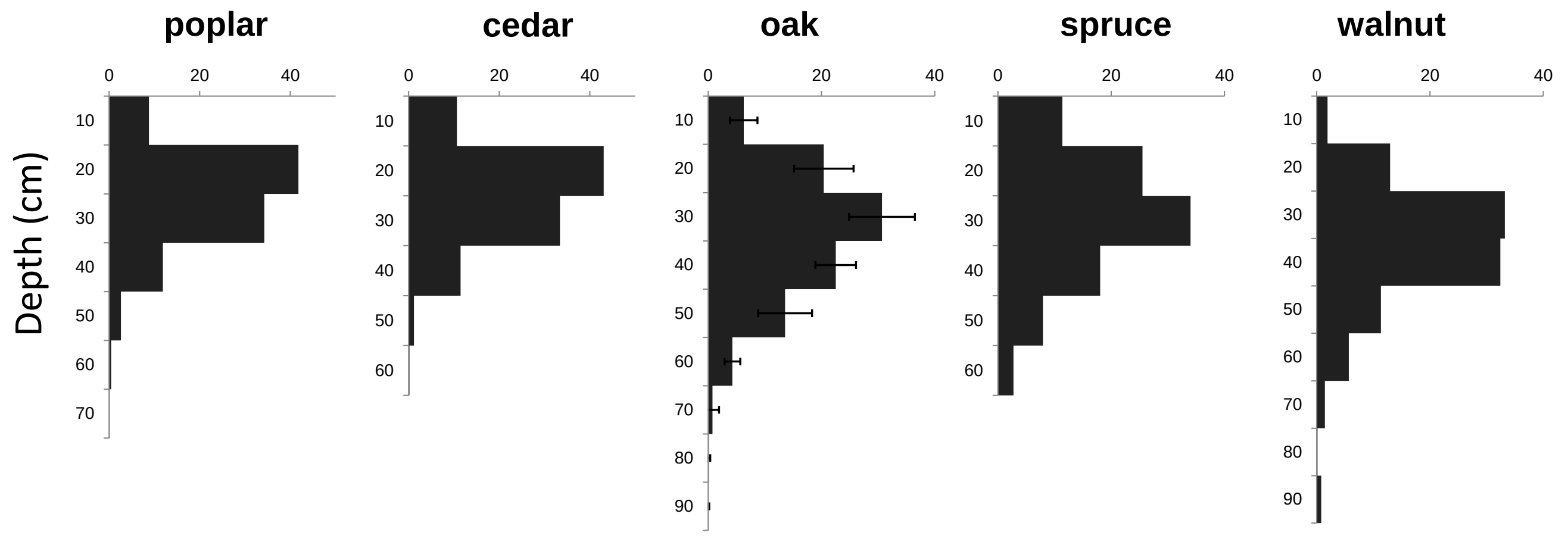

Figure 9. Frequency distribution (%) of radar detected root locations with depth in 10cm increments for each tree species.

Expected results and implications

We anticipate interspecific variance in belowground biomass allocation patterns in rooting depth and directionality. Results could lead to management decisions of species selection or planting design to minimize belowground competition with crops. We also anticipate relationships between subsurface images and root size. Furthermore, distribution and biomass data can be combined with species-specific root carbon content data, increasing precision in belowground biomass estimation and improving carbon sequestration calculations in these tree-based intercropping systems.

Acknowledgments

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