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EVALUATING TREE ROOT DISTRIBUTION IN A TREE-BASED INTERCROPPING SYSTEM WITH USE OF GROUND PENETRATING RADAR

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ABSTRACT

Within agroforestry systems, tree root architecture is a driver of important ecological processes such as belowground nutrient flows and C storage. Yet the belowground component of trees remains largely under-studied due to methodological restraints. Conventional subsurface sampling can overlook the heterogeneity of root systems, while complete excavations are destructive and unrepeatable. Thus, there is a need to develop non-intrusive technologies, such as ground penetrating radar (GPR), to measure root systems *in situ*. In this study we used GPR to detect coarse root distributions below five tree species (*Quercus rubra*, *Juglans nigra*, *Populus* sp., *Picea abies*, and *Thuja occidentalis*) at a temperate tree-based intercropping site in Guelph, Ontario. GPR geo-imaged transects were collected in 4.5 × 4.5m grids that were centered on 15 individual trees. Subsequently, tree roots were identified across all geo-images (visualized as radar signal reflections) providing 3-dimensional root distribution data for each target tree. Roots detected by GPR accounted for approximately 80% of large coarse roots (≥1cm) and 40% of small coarse roots (<1cm) that were later exposed in a subset of matched soil profiles. Significant inter-specific variations of coarse rooting depth preferences were detected. Additionally, preliminary analyses indicate different tree rooting patterns below the crop rows. To determine fine root distributions, fine roots were extracted from soil cores collected from the tree root study plots. Preliminary analysis indicates fine root length densities vary across species predominately in the upper 20cm. Limitations will be identified and applications will be discussed of GPR to answer ecological questions within agroforestry systems. Notably, we will highlight results from our complementary study that used the same GPR data to effectively estimate belowground biomass.

Keywords: tree root distribution, ground penetrating radar, carbon sequestration, belowground biomass

INTRODUCTION

Root systems constitute over 20% of total tree biomass (Brunner and Godbold 2007) and are critical for incorporating organic matter belowground (Jobbágy and Jackson 2000, Rasse *et al*. 2005). Within tree-based intercropping (TBI) systems, variations in root system biomass allocation and distribution may be dictated by site conditions and management practices (Kuyah *et al*. 2012). However, estimations of the belowground extent of tree root systems are conventionally applied from root:shoot ratios and allometric equations according to forest type and biome (e.g. Jackson *et al*. 1996, IPCC 2006). Thus tree species and site-specific belowground data are required for more accurate calculations of carbon dynamics and improved tactical approaches for TBI site design and management.

Knowledge of belowground dynamics in TBI systems is restricted in large part by the methodological limitations of studying roots *in situ* (Norby and Jackson 2000). Therefore, there is a need to develop techniques that measure belowground biomass non-destructively and also capture the heterogeneity of tree root systems. Ground penetrating radar (GPR) has been used as a non-intrusive geo-imaging tool to detect the presence of coarse roots *in situ* (Hruska *et al*. 1999, Butnor *et al*. 2001, Isaac and Anglaaere 2013). Radar signals can reflect where there is sufficient difference in dielectric permittivity such as at the root-soil interface, or more specifically, when water content within the root is greater than the surrounding soil (Hirano *et al*. 2009). The GPR unit emits radar pulses into the ground and records any reflected return signals. While the unit is moved across a buried coarse root, the successive reflected radar signals produce a hyperbolic reflection visualized in the interpreted geo-image of the subsurface.

The objective of this study is to assess the root distributions for five intercropped tree species (*Populus deltoides x nigra* DN-177 (poplar hybrid), *Quercus rubra* (red oak), *Juglans nigra* (black walnut), *Picea abies* (Norway spruce), and *Thuja occidentalis* (white cedar)) within a TBI system in southern Ontario. To do so, we identify the coarse root distribution in the subsurface by analyzing geo-imagery produced from GPR and we determine fine root distribution with the use soil core sampling.

METHODS

The study site is located at the University of Guelph Agroforestry Research Station, Ontario, Canada (43°32′28″N latitude, 80°12′32″W longitude). The five intercropped tree species selected for the study (*Populus* sp., *Q. rubra*, *J. nigra*, *P. abies*, and *T. occidentalis*; *n*=3) were approximately 25 years old. The trees were planted in rows with 6m stem spacing (except *T. occidentalis* with 1m spacing). Crop rows are 12.5 or 15m wide and under an annual rotation of *Zea mays* (maize), *Glycine max* (soybean), *Triticum aestivum* (winter wheat) or *Hordeum vulgare* (barley) (Thevathasan & Gordon 2004). Soil at the site is sandy loam, which is conducive for GPR study.

We used a 1GHz GPR unit (Noggin plus, Sensors and Software Inc., ON, Canada) to geo-image the subsurface surrounding the base of each tree. Geo-image data were collected in a 4.5 × 4.5m grid design with 10 cm transect spacing, equating to 92 geo-images that were orientated either perpendicular to the tree and crop rows or parallel to the rows. Radar signal reflections from coarse roots were visually identified in the geo-images (EKKO_Interp, Sensors and Software Inc.) providing x, y, z point pattern data for distribution analyses (Isaac and Anglaaere 2013). Accuracy of coarse root detection was tested with exposed soil profiles that matched a subset of geo-images. The velocities of radar signals through the subsurface were measured near each target tree (0.06 to 0.10m ns^{-1}) and used to calibrate the vertical scale of geo-images for accurate interpretation of depth to detected coarse roots.

The fine root distribution was determined from soil cores collected within the tree study plots to a depth of 60cm. Fine roots were removed from soil through wet sieving (Livesley *et al*. 1999) and subsequently measured for root length density with the use of a flatbed scanner and image analysis software (WinRHIZO, Regents Instruments Inc., QC, Canada).

RESULTS AND DISCUSSION

During this study, GPR detection rates of coarse roots were approximately 40% for small coarse roots (<1cm) and 80% for larger coarse roots (≥1cm) with errors highlighting GPR detection limitations relating to root diameter, orientation, depth, and proximity to adjacent roots. There were significant inter-specific variations between the rooting depth preferences for the deeper root systems of *J. nigra* and *Q. rubra* and the shallower root system of *T. occidentalis* (P<0.05). Interestingly, a different pattern emerges for rooting depth preferences for detected coarse roots below the crop rows, with preliminary results indicating significant inter-specific variations only at depths of 40 to 60cm. Moreover, exploratory spatial analyses indicate differences in rooting patterns between the treed and cropped rows. The fine root distribution data complete the quantification of the root system extent with preliminary results indicating fine root length density variations between species, most notably in the top 20cm of soil.

Overall, the utility of GPR proved effective for non-intrusive study of coarse root distribution and has potential to be functionalized in future research for answering important ecological questions within TBI systems. Currently, root carbon analysis and the results from a companion study, which used the same GPR data to estimate belowground biomass, can further enhance our understanding of belowground biomass and carbon dynamics in this TBI system. Other applications include predicting water uptake zones with the use of GPR detected root distribution in complement of isotopic signatures ($\delta^{18}O$) of the soil profile and non-photosynthetic tree tissue (Isaac and Anglaaree 2013).

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REFERENCES

Brunner I. and Godbold, D.L. 2007. Tree roots in a changing world. Journal of Forest Research 12:78–82.

Butnor, J.R., Doolittle, J.A., Kress, L., Cohen, S. and Johnsen, K.H. 2001. Use of ground-penetrating radar to study tree roots in the southeastern United States. Tree physiology 21:1269–78.

Hirano, Y., Dannoura, M., Aono, K., Igarashi, T., Ishii, M., Yamase, K., Makita, N. and Kanazawa, Y. 2008. Limiting factors in the detection of tree roots using ground-penetrating radar. Plant and Soil 319:15–24.
Hruska, J., Cermák, J. and Sustek, S. 1999. Mapping tree root systems with ground-penetrating radar. Tree physiology 19:125–130.
IPCC. 2006. Forest lands. In: Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories. Institute for Global Environmental Strategies (IGES), Hayama, Japan, p. 83.
Isaac, M.E. and Anglaaere, L.C. 2013. An *in situ* approach to detect tree root ecology: linking ground-penetrating radar imaging to isotope-derived water acquisition zones. Ecology and Evolution 3:1330-1339.
Jackson, R.B., Canadell, J., Ehleringer, J.R., Mooney, H.A., Sala, O.E. and Schulze, E.D. 1996. A global analysis of root distributions for terrestrial biomes. Oecologia108:389–411.
Jobbágy, E.G. and Jackson, R.B. 2000. The Vertical Distribution of Soil Organic Carbon and Its Relation to Climate and Vegetation. Ecological Applications 10:423–436.
Kuyah, S., Dietz, J., Muthuri, C., Jamnadass, R., Mwangi, P., Coe, R. and Neufeldt, H. 2012. Allometric equations for estimating biomass in agricultural landscapes: II. Belowground biomass. Agriculture, Ecosystems & Environment 158:225–234.
Livesley, S.J., Stacey, C.L., Gregory, P.J. and Buresh, R.J. 1999. Sieve size effects on root length and biomass measurements of maize (*Zea mays*) and *Grevillea robusta*. Plant and Soil 207:183–193.
Norby, R.J. and Jackson, R.B. 2000. Root dynamics and global change: seeking an ecosystem perspective. New Phytologist 147:3–12.
Rasse, D.P., Rumpel, C. and Dignac, M.F. 2005. Is soil carbon mostly root carbon? Mechanisms for a specific stabilization. Plant and Soil 269:341–356.
Thevathasan, N.V. and Gordon, A.M. 2004. Ecology of tree intercropping systems in the North temperate region: Experiences from southern Ontario, Canada. Agroforestry Systems 61–62:257–268.