Use of Ground-Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) to study tree roots volume in pine forest and poplar plantation

G.F. Morelli[1], T. Zenone[2-3], M. Teobaldelli[2], F. Fischanger[1], M. Matteucci[2] and G. Seufert

[1]Geostudi Astier. Livorno (Italy)

[2]European Commission. DG Joint Research Centre Institute for Environment and Sustainability

Climate Change Unit. Ispra (VA) Italy

[3]Department of Forest Environment and Resource University of Tuscia Viterbo.

Corresponding authors:
Gianfranco Morelli Phone +39 0586 864734 E-mail: gianfranco_morelli@fastwebnet.it

1. Introduction

The evaluation of tree root biomass is significant and difficult to survey accurately. Traditional approach used for roots biomass harvest (e.g., soil cores and trenches) provide reasonable accurate information but they are destructive in nature, labour intensive, and limited whit respect to soil volume and surface area that can be assessed. Data derived from traditional root extraction approaches are also generally limited to root biomass averages across plots or treatments rather than information on root distribution. Sampling needed to detect difference among treatments can be expensive as well as time consuming for technical personal. For the above reason test and develop new indirect tools for roots biomass survey appears of leading importance.

2. Objectives

In this study we have assessed the possibility to use Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) as a root volume indirect survey investigation.
Although previous studies have demonstrated the potentiality of these methodology to detect root systems (J. R Butnor et al 2001 J. Hruska et al 1999 L. Wielopolski, et al 2000) up to now few research (Stokes et al. 2002) has tried to compare the GPR and ERT response with direct observations of the entire root system.

3. Material and methods

3.1 Experimental site

Two experimental sites have been investigated in this study: a poplar plantation located in Zerbolo' (Pavia Italy) (45°12'03" N; 9°03'40" E) and a pinewood forest within the Regional park of San Rossore (Pisa Italy) (43°43'40" N; 10°17'04" E)
Both sites are part of the CarboEurope network, equipped with a eddy covariance flux tower.The poplar stand (*Populus* x *euramericana* clones I-214, spacing 6 x 6 m, density 270 plants ha^{-1}) was planted in a plain area of 120 ha, inside the Basin of Ticino River, characterized by alluvial soil (mostly clay, stone and lime). It was clearcutted in april 2005.
On the other hand, the pinewood forest (Pinus *pinaster,* Pinus *pinea,* Quercus *ilex*), is growing in a strip plantation, at 800 m distant from seashore. The area, characterized by the

presence of old coastal dunes with an elevation less than 4 m, is mostly formed by sand and slime. After a preliminary investigation of horizontal and vertical structures of the sites (basal area at breast height, n. of trees, total height), three trees were selected, in each stand, on the basis of their diameter at breast eight (DBH) for geophysical investigations.

3.2 ***Ground penetrating radar***

The Ground penetrating radar (GPR) is an ultra-wideband imaging technique widely used for subsurface exploration and monitoring, in civil engineering, archaeology and forensic examinations, pipeline, cavity and tunnel detection. GPR is non-invasive, performed with hand-held portable units, and has the highest resolution of any subsurface imaging method. In this case we propose to perform a 3D GPR survey, where the density of survey lines is increased by acquiring data in different directions, resulting in 3D maps that can detect roots or other features regardless of their direction. The unsaturated sand and silt layers that characterize the top soil allow good radar penetration, even at the high frequencies needed to have the best detail, down to at least 1.5-2 meters.

3.3 ***Electrical resistivity tomography***

The Electrical Resistivity Tomography (ERT) is a method that calculates the subsurface distribution of the volumetric resistance from a large number of measurements (current and potential) made from electrodes placed in an arbitrary geometric pattern. For geophysical applications ERT uses electrodes on the ground surface or in boreholes. By accurately calculating the soil resistivity it is possible to detect, water, clay layers, voids, but it also possible to reconstruct sections of the ground that can be used to choose and calibrate the parameters for GPR surveys. ERT surveys that employ large number electrodes arranged in grids or sets of lines, as in this case, can be used to reconstruct a 3D model of the subsurface, and allow the mapping of complex structures like root systems.

3.4 Direct measurements

The selected roots system were entirely excavated using AIR-SPADE® Series 2000; this system use a proprietary, synergistic combination of supersonic jets of air and high flow pneumatic vacuum transport. Supersonic air jets are extremely effective at penetrating most types of soil, but are harmless to all types of non-porous buried objects. This technique allow to dig out the entire roots system without damage it (E. T. Smiley 2001) After removal of shallow soil roots were pulled out using a digger. In order to acquire morphological information on root system to be compared with the GPR and ERT methods: poplar roots were scanned using a spot Zoller+Fröhlich GmbH Laser Measurement System LARA 53500. Ten different laser scans were made for each root; and after were elaborated using the software JRC–Reconstructor ®; orthogonal sections, with respect to the central axis of the taproot, were created and exported in dxf format (CAD). Pine roots were completely excavated and several digital pictures were taken.

4. Selected Results

4.1 ***Ground Penetrating Radar***

In test sections analyzed around the poplar trees (Fig 1) GPR with high frequency antennas showed to be able to detect roots with very small diameters and different angles, with the geometry of survey lines ruling the intensity of individual reflectors. A grid of parallel

lines in two directions was then acquired around each of the test trees, to try to achieve a sort of 3D reconstruction of the root system. The comparison with the Laser scan point-cloud of the extracted roots (Fig 2), has proven that the potential of high density 3-D GPR to map the entire system in unsaturated soil, with a strong preference for sandy and silty terrain, and problems arising when clay is predominant, and also when “clutter” produced by gravel and pebbles is mixed with the response of roots.
The Comparison between 3D rendering of Laser-scan point cloud and GPR sections. The red points, present in GPR section, represent the root position.

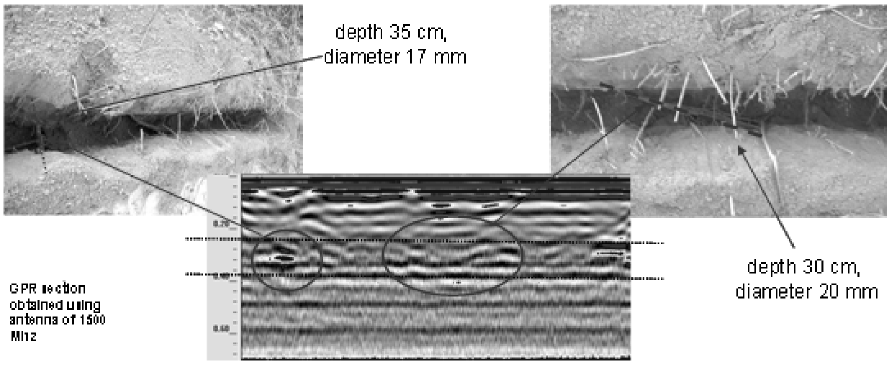

Fig 1.Comparison between root position and radar profile. Vertical scale is depth (m). The profile was excavated and the sources of radar reflection detected

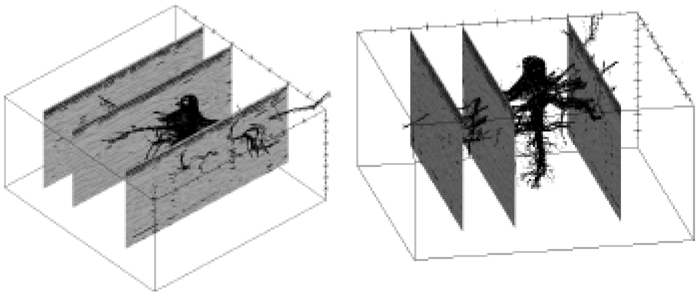

Fig2. Comparison between 3D rendering of Laser-scan point cloud and GPR sections. The red points, present in GPR section, represent the root position.

4.2 Electrical Resistivity Tomography

Three-dimensional reconstructions using grids of electrodes centered and evenly spaced around the tree have been used in all cases (poplar and pine), and repeated in different periods (April, June, September) to investigate the influence of water saturation in the results obtainable. While it was difficult to get much more than (detailed) stratigraphic information around poplar trees, the work performed on the pine trees shows clearly that the distribution of larger diameter roots has a strong correlation with the electrical resistivity 3-D models. Most of all (Fig 3) the use of difference images between successive sets of data revealed to be a powerful method, as the roots act like a “filter” for water thus causing a local increase of resistivity after a wetting period.

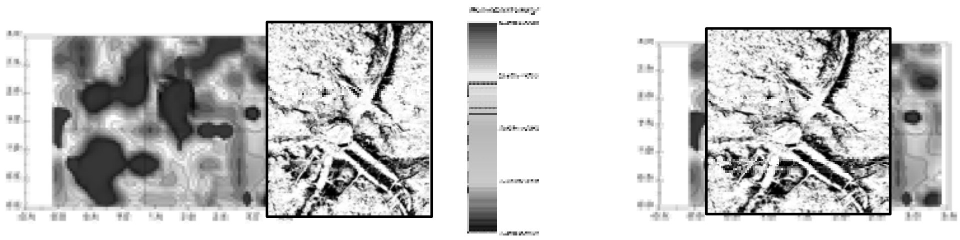

Fig. 3 Plan view slices of 3D resistivity percent increment (difference calculated between results obtained in dry and wet conditions) compared with view from top of unveiled roots system

5. Conclusions

Geophysical surveys can reveal a useful approach to roots investigation, both in describing the shape and behavior of the roots in the subsoil. To achieve the better results this paper underlines the need of integrating different techniques: GPR method is able of detecting with higher resolution the distribution of the tree roots in the subsoil. Three dimensional ERT can be useful in correlating the recovered resistivity distribution with root volumes. In particular the extraction of volumes of resistivity percent increment between dry and wet conditions in the subsoil around the trees seems a parameter that can be directly related to the volumes of roots. Further studies should focus on two directions: first, the improvement of a standard field-procedure to carry on the geophysical surveys; second, the development a statistical processing tool to relate root biomass to geophysical parameters.

Acknowledgements

This research was partly funded by the CarboEurope IP project (EU-Contract No. GOCE-CT-2003-505572) and by the JRC-IES-CCU-Action 24002 - Greenhouse Gases in Agriculture, Forestry and Other Land Uses - GHG-AFOLU. We would thank all colleagues of the Climate Change Units that helped us during the direct measurements.

References

- J. R. Butnor, J. A. Doolittle, L. Kress, S. Cohen and K. H. Johnsen (2001) Use of ground-penetrating radar to study tree roots in the southeastern United States Tree Physiology 21, 1269–1278

- Hruska J, Cermak J, Sustek S (1999) Mapping tree root systems with ground-penetrating radar. Tree Physiol. Feb;19(2):125-130

- L Wielopolski, G Hendrey, J Daniels, M McGuigan (2000) Imaging tree root systems in situ. D.A. Noon, G.F. Stickley, and D. Longstaff (ed.) Proceedings of the 8th International Conference on Ground-Penetrating radar, Gold Coast, Queensland, Australia, 23–26 May 2000. Proceedings of SPIE—the International Society of Optical Engineering, Bellingham, WA. 4084:642–646

- Stokes A. Fourcaud T. Hruska J. Cermak J. Nadyezhdin N. and Praus L. (2002) An evaluation of different methods to investigate root system architecture of urban trees in situ: I. Ground penetrating radar. Journal of Arboriculture 28(1): page 1-9