Use of ground-penetrating radar as a non invasive method to study the growth, dynamic and biomass contained in the roots of typical trees of tropical rainforest.

Frederico Ricardo F. R. de Oliveira e Sousa (PHYGEO – Soluções em Geofísica e Geotecnologia – phygeojr@gmail.com)
Amanda Almeida Rocha (PHYGEO – Soluções em Geofísica e Geotecnologia – phygeojr@gmail.com)
Welitom Rodrigues Borges (Docente do Instituto de Geociências da UnB – welitom@unb.br)

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Abstract

The objective of this study is to observe the application and performance of the ground penetrating radar (GPR) as a non invasive method of estimating the biomass and distribution of the roots of Brazilian forest trees planted in location propitious for radar investigation. The GPR 2D profiles where collected with 200 MHz shielded antennas, with the intention of obtaining information about the deeper roots. The results presented in the form of GPR signal amplitude maps show the behavior of the plant's roots, indicating the position and the average volume of the Guapuruvu roots with precision.

Introduction

Roots of plants where always interpreted in the geophysical surveys as excess data to be eliminated from the data processing, since they were not the object of study (Doolittle e Miller 1991, Barker e Doolittle, 1992, Silveira *et al.*, 2010). Nowadays studies have begun to innovate in this sense, using GPR to map thick oak roots (bigger than 3 cm in diameter) that are over 50 years old (Hruska *et al.* 1999 *apud* Butnor *et al.* 2001). From this pioneer study, geophysicists such as Butnor *et al.* (2001), detected tree roots with a diameter of up to 0,5 cm in the southeast of the United States using elevated frequency antennas (above 1 GHz). In Germany, Vianden *et al.* (2010) began to apply this technique to study the behavior of roots in urban areas. In Brazil, environmental engineers have complained that the absence of indirect root study techniques, as, for example, Silva (2007), when she alleged that there is little study of thick root biomass in humid tropics, and that these few studies uses fixed parcels to estimate the biomass. Moreover, that there is no papers of allometric models to estimate, in indirect form, the biomass of thick roots in tropical regions. In this sense, this work shows preliminary results obtained by GPR in an area where there are big trees (Guapuruvú) in the University of Brasília (UnB).

Methodology

The case study was the Guapuruvu (*Schizolobium parahyba*) tree legume characteristic of the Atlantic forest, but also occurs naturally in the Amazon Forest (EMBRAPA, 2009). The trees find themselves in the UnB campus, near to the Central Institute of Science (**Figure 1**), in Brasília/DF. These are between 10 and 15 meters tall and some roots are surfaced, which makes evident their typical lateral growth (**Figure 2**). Studies from EMBRAPA (2009) towards the evaluation of native species for the environment recovery in the Amazon indicate that Guapuruvu is the native species that represents the best results: their seedling can reach up to 1,6 m high after the first year of growth.
The improvement of the roots' biomass estimates in reforested trees is an important stage in the measuring of carbon absolved by the trees, a process which is intimately related to the Kyoto Protocol and the global carbon trade, which is in rise. The report State Trends of the Carbon Market published by the World Bank in 2010 proved a 6% high in the world carbon trade in relation to the previous year, with total negotiated values in the order of US$ 144 billion.

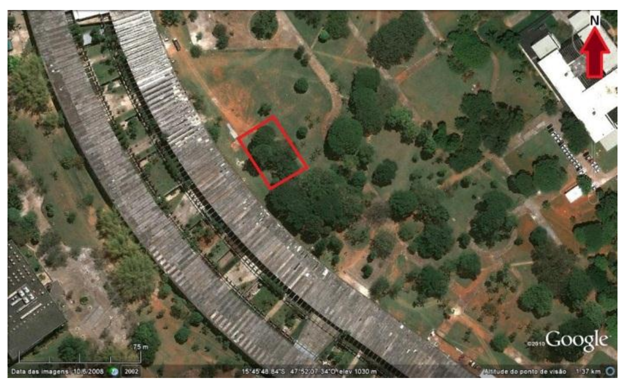


Figure 1 – Location of the examined trees (Source: Google Earth).

Figure 2 – Group of Guapuruvus indicated in **Figure 1,** planted beside the Central Institute of Science in University of Brasilia (ICC/UnB).

The Distrito Federal's soil represents the main class of soil of the "cerrado" region (Buol & Cline, 1973 *apud* Martins *et al.*, 2008). The region has three classes of soil which are the most important, named Red Latosol (RL), Red-Yellow Latosol (RYL) and Cambisol (CX). Their territorial representation in the Distrito Federal is of 85%. The Latosols represent 54.47% of the area, divided by RL (38.63%) and RYL (15.84). The RL class occurs primarily in the tops of the plateau, main dividers with their level tops, in the Paranoá basin and in the Preto basin (Martins *et al.* 2008). The quantity of clay, salt, or percentage of slurry or water in the soil influence directly the attenuation of the radar signal (Doolittle e Butnor, 2009), which is the reason why the choice of the central frequency in which the GPR will operate has to be always made after soil identification.

According to Doolittle e Butnor (2009), the most utilized antennas for soil investigation have central frequency of 100 to 500 MHz. Antennas of high frequency gives better results in dry soil and electrically resistive. In soil of reasonable attenuation, in which the penetration of signals in depth is limited, these antennas of high frequency produces depth investigation comparable to the antennas of low frequency. Antennas with frequency of 900 MHz to 1.5 GHz have been used for shallow investigation and in sandy soil. For organic soil, responsible for a high attenuation of the electromagnetic signal, where great depth investigation are necessary for the study being developed, the low frequency antennas, between 70 and 200 MHz, are commonly used. The **Table 1** shows the variation of physical properties of some soils in regard to their composition.

Table 1 – Interval of Dielectric constant, conductivity and magnetic permeability. (Annan, 1992; Porsani, 1999; Prado, 2000).

Materials	***K***	***μr***	***σ_0 (mS/m)***
Sand soil	2.6	1	0.14
Wet sand soil	25	1	6.9
Clay soil	2.4	1	0.27
Wet clay soil	15	1	50
Root	3 - 5	1	0

The GPR projects on electromagnetic pulse towards the interior of the soil, which interacts with the diverse element – conductor and dielectric - there present. The roots are formed by molecules, which are constituted by the particles charged with electric charge (atom nucleus and electrons). This means that the molecules on the surface of the roots interact with the electromagnetic waves. In this process, the balance change suffers a polarization, which in turn results in the reflection of the pulse, captured by the GPR receiving antenna.

As indicated in the numbers of **Table 1**, the constant dielectric represents the physical characteristics particular to the means in which the pulse of the radar is running. According to Cunha (2009), the dielectric constant becomes the central point when working with electromagnetic methods of high frequency (>1MHz). For frequencies between 1MHz e 2GHz, the water content govern the dielectric properties of the material, once the value of the permissiveness of water is ten times greater than the permissiveness characteristic of roots. Hence the geophysical GPR equipment is capable of characterizing the material being studies as red latosol due to it's constant dielectric characteristic, as well as locate the position and dimensions of the roots of the Guapuruvu as a non-invasive way.

The GPR SIR-3000 was the model used (manufactured by the *Geophysical Survey Systems, Inc.* Company) linked to a shielded antenna with a central frequency of 200 MHz and a survey wheel (**Figure 3**). The GPR data where obtained by the common offset technique, which permits the visualization of the underground reflectors. The data were collected along 90 meters, equally spaced in 1 meter, in an area of 1800 m² (90 m x 20 m).

Figure 3 – Picture shows the GPR data acquisition in the proximity of a Guapuruvu with a 200MHz shielded antenna linked to a SIR-3000 equipment.

After the GPR data acquisition, the data where processed in the ReflexW software, version 5.0. The processing stage where applied in accordance to the characteristics of the data and depended, mainly, of the interpreter. Once chosen the processing flux for a GPR session, the same is applied to the other session in the same way (Borges, 2010). The soil electromagnetic velocity obtained was 0.072m/ns, based in the hiperbolic event related to the diffraction from the root. After the stage of migration, the data were converted in the true amplitude to the trace envelope.

The 2D profile of each line of acquisition were interpreted within the geometric patterns of reflection of the electromagnetic pulse, making is possible for estimate of the diameter of the roots of the Guapuruvu. With the interpolation of the results obtained from the 2D profile, it was possible to elaborate a 3D map of the Guapuruvu root system.

Results

The results obtained with the antenna of 200MHz enable the identification of hyperbolic diffractions related to the roots of trees, the maximum depth of 1.5 meters (**Figure 4**). The radar signal was down to a depth of 8 meters, but did not notice roots to that depth.

Depth slices were generated (**Figure 5**), allowing a view of the lateralized growth pattern of the Guapuruvu's roots. In **Figure 5** is possible to visualize 5 large roots with diameters ranging from 10cm to 30cm (**Figure 4**), and average length of 26 meters**.** According to Lorenzi (2002), Guapuruvu's wood has low density, 0.32g/cm³ . Based on the dimensions of the roots obtained with the GPR data processing, it was possible to calculate volume (0.82m³ each one, approximately) and weight (261.38 kg each one, approximately) of theses roots.

According to Silva (2007), the water content weighted by shares of a tree including its roots, is 41.6%, with an uncertainty of 2.8%. Therefore, subtracting the contribution of the total water mass, we obtained a value of 763 kg, as an estimate for the total biomass of the roots of Guapuruvus the study area.

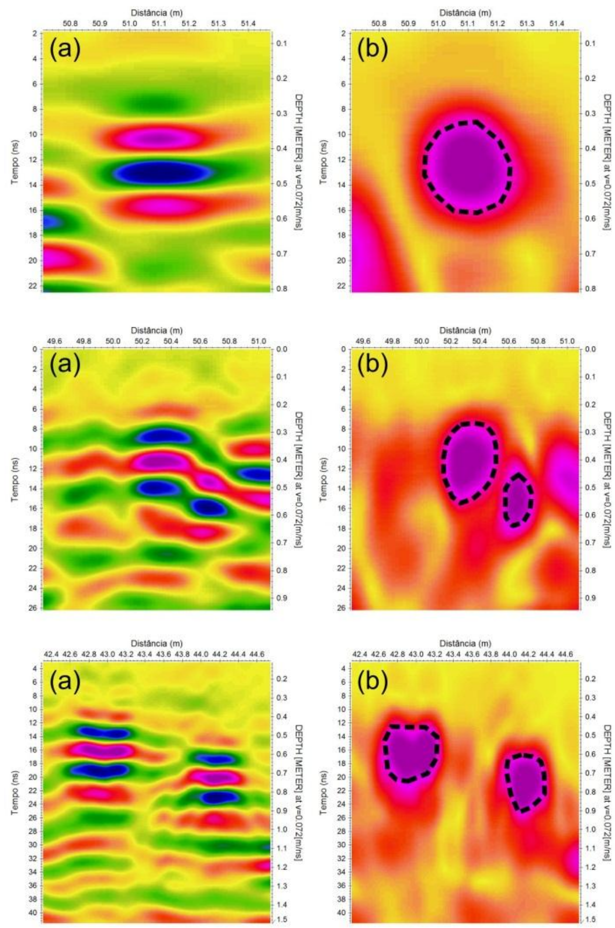
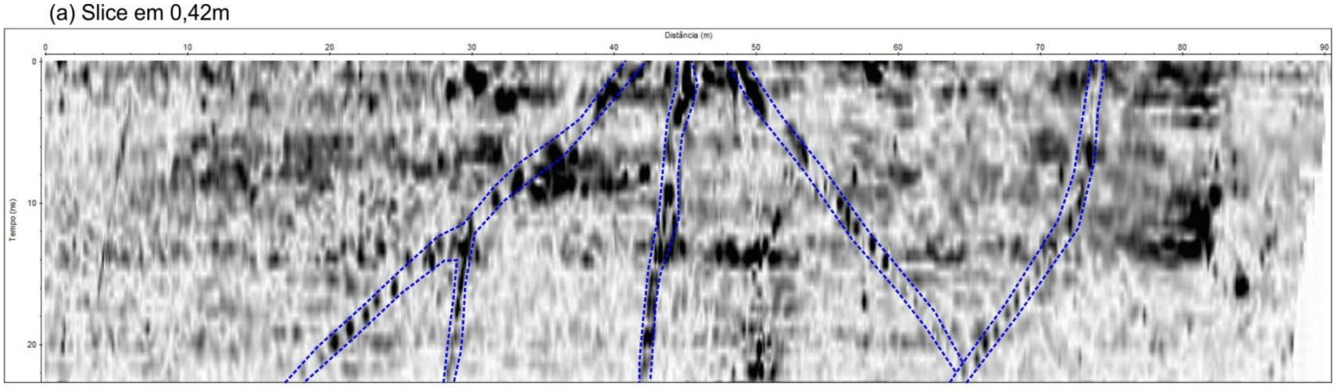


Figure 4 – GPR sections showing the reflections patterns related to the Guapuruvu's roots. (a) Sections of GPR showing the true amplitude of the electromagnetic signal. (b) GPR data in the form of the trace envelope with the interpretation of the hit area of the roots (dashed line).

(a) Slice em 0,42m



(b) Slice em 0,66m

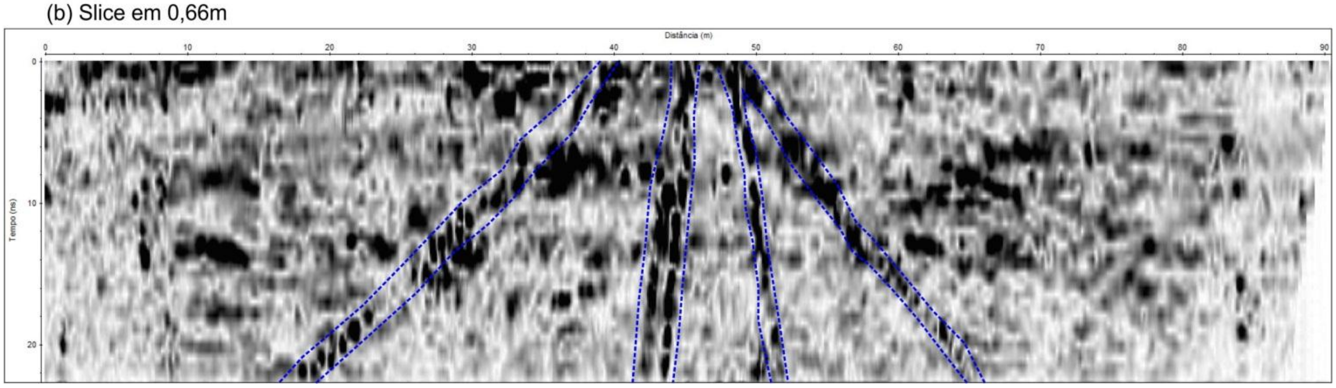


Figure 5 – Depth slices performed in the volume of GPR data after the interpolation of 2D profiles showing the pattern of root growth of Guapuruvu. (a) Depth slice conducted at a depth of 0.46m. (b) Depth slice conducted at a depth of 0.66m.

Conclusions

The results obtained show that the GPR is an excellent method to estimate, in an indirect form, the growth, dynamic and biomass of the thick roots of some of the typical trees of the Brazilian forests, such as the Guapuruvus.

The main advantage of the GPR, when compared to the traditional techniques for biomass estimation, is that there is a reduction of costs, precision of the measurements and the work takes up little time. It is important to stress that the GPR is a geophysical technique of minimum environmental impact.

It is important to point out that this work is a preliminary study, and future studies with the GPR to calculate biomass of Amazon tree roots will be made and compared to the technical results of destructive sampling. This comparison between radar and traditional techniques is the crucial phase to consolidate the GPR in this type of environmental survey.

Despite good results verify the antenna of 200MHz, we recommended that the use of antennas with elevated frequency (above 900 MHz) to provide the greater level detail (roots with diameter up to 0.5cm) in the first 30 cm of depth.

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