IN-SITU CASSAVA ROOT SIZE MEASUREMENT USING GROUND PENETRATING RADAR (GPR)

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Abstract

Ground penetrating radar (GPR) has been used increasingly to measure the growth of coarse roots (>2 mm diameter) of woody trees and other large plants. We used high-frequency GPR (1000 MHz) to measure the growth of the storage roots of two cassava cultivars in Flanagan/Drummer soils periodically over the course of three months during the 2017 field season. Growth conditions included plots with elevated concentrations of carbon dioxide ([CO_2] = 600 ppm, test) and ambient carbon dioxide levels ([CO_2] = 400 ppm, control). We had 168 plants of each cultivar, which were divided into 8 subplots (12 m^2) containing 21 plants per subplot. Four of these subplots were treatment plots (elevated [CO_2]) and four were control (ambient [CO_2]). We used a consistent GPR measurement grid for data collection at every cassava plot throughout the growing season to ensure we were measuring at the same location with each GPR pass. After the baseline measurement, 1-4 plants were excavated each month of the season to ground-truth the GPR data.

The GPR data were processed using EkkoProject 5 and visualized in 3-dimensions using Voxler, which allowed for volumetric modeling. The locations of the roots were interpreted and annotated at each time interval. We show qualitatively that the increase in biomass created by cassava plants in an elevated-CO_2 environment can be captured non-destructively using GPR.

Introduction

Project Background

The Cassava Free-Air CO_2 Enrichment (Cassava FACE) experiment seeks to increase knowledge around crops needed to increase food security around the world through research on cassava (*Manihot esculenta*). Cassava is the second-fastest growing staple crop in the world in terms of production tonnage, and is consumed by about 800 million people worldwide (UN FAO, 2013). It is the staple of nearly 80% of Africa (FSN Forum, 2009). As CO_2 concentrations ([CO2]) rise, future environmental conditions are likely to be warmer (IPCC, 2013). Higher [CO2] tends to increase biomass in C3 plants like cassava (Rosenthal et al., 2012). Cassava is well suited to increases in global temperature and is known for its resilience to drought and poor soils; however, pests and diseases may also increase with elevated [CO_2] (DeLucia et al., 2008), which already challenge cassava productivity in Africa. Consequently, additional research is needed to better understand the growth and production of cassava in current and future production environments. FACE experiments are designed to allow crops to be grown at elevated CO_2 levels while still under realistic field conditions (Ainsworth, 2010). In order to monitor the growth of the plants throughout the season, several methods were employed to measure various parameters of plant growth. We investigate GPR as a potential technology to non-destructively measure the growth of cassava roots in two cultivars under elevated and ambient [CO_2] levels.

Figure 1: Our wood frame pinned into the soil around 21 cassava plants in an elevated [CO_2] plot. Teal-colored tubes (and black feeder tubes) carrying the CO_2 can be seen in the background. The black tubes on the ground in the frame are drip-irrigation tubes that were removed before taking GPR measurements. The frame is about 4 m x 3 m.

Methods

Ground penetrating radar (GPR) is a shallow geophysical tool used for imaging the objects in subsurface environments. In the most common GPR geophysical techniques (i.e., common midpoint and common offset), radio waves are transmitted into the ground and received via antennae after reflecting off of objects, strata, soil, and other dielectric interfaces in the subsurface. For GPR measurements in general, the higher the frequency of the electromagnetic pulse transmitted, the greater the precision of the signal. However, higher frequencies require exponentially more power to reach deeper targets (Sensors and Software, 1999).

We used high-frequency GPR (1000 MHz) to measure the growth of the storage roots of two cassava cultivars grown near Urbana, IL in Flanagan/Drummer soils once a month over the course of three months during the 2017 field season. Flanagan/Drummer soils are relatively high in clay content, and are not considered ideal GPR matrices, especially since the target (cassava roots) has similar electrical properties.

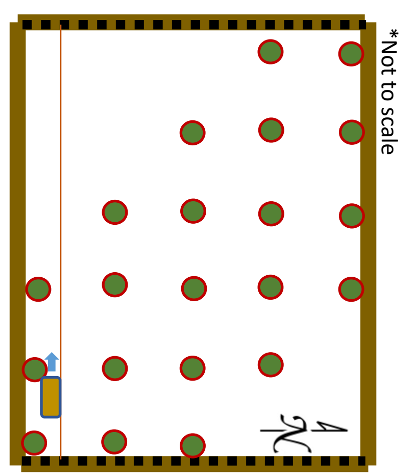

Figure 2: Diagram showing the top-down view of our frame. Green circles indicate plants. The dark yellow box is the instrument and the orange line is a guide string. Black dots represent guide holes drilled on 5 cm centers.

Subsurface targets are generally easier to delineate using GPR when there are large differences in the electric properties between the matrix and the target.

Figure 3: Excavated roots of a cassava plant shown from the side.

Growth conditions included plots with elevated concentrations of carbon dioxide ([CO_2] ≈ 600 ppm, treatment) and ambient carbon dioxide levels ([CO_2] ≈ 400 ppm, control). One hundred sixty-eight plants of each cultivar were divided among eight subplots (~16 meters^2) containing twenty-one plants per subplot (Figure 1). Four of these subplots were treatment plots (elevated CO_2) and four were control (ambient CO_2). We used a consistent GPR measurement grid for data collection at every cassava subplot throughout the growing season to ensure we were measuring at the same location with each GPR pass (Figure 2). A string was stretched between two same-numbered holes on either end of the frame, and was moved 5 cm after each pass. When the instrument reached a plant stem, the instrument was moved 15-25 cm to the other side of the stem, where measurements were continued. All profiles were collected in a single direction. After the baseline measurement, 1-4 plants were excavated each month of the season (3 times in total, July – September) to ground-truth the GPR data (Figure 3). For the third and final harvest, photos were taken of four plants per subplot and the orientations of the plants were noted to aid interpretation of the GPR data.

The GPR data were processed using EkkoProject 5 and visualized in three-dimensions using Voxler. The locations of the roots were interpreted and annotated at each time interval. This aided in interpretation of noise, which was significant because there was not a large difference between the electric permittivity of the (often moist) soil and the roots that we hoped to measure.

Results

The data processing was standardized across all of the GPR lines that were gathered to maintain consistency. For each GPR profile this included: dewowing, gain application, background subtraction, bandpass filtering, migration, and envelope creation. A single propagation velocity was determined for each subplot through hyperbolic velocity-fitting. These values were all at or near 0.1 m/ns $\pm$ 0.02 m/ns. Once all the lines had been processed, these were exported into two-dimensional (slices) and three-dimensional formats.

The data were especially noisy in the first 0-10 cm below the ground surface (bgs) where there was a large number of desiccation cracks and other structures that interfered with the GPR signal reflection. In order to mitigate this noise, an additional gain was applied after the data were initially processed: a Gaussian/normal curve centered at $\mu = 0.35$ m bgs with a standard deviation of $\sigma = 0.07$ m (Figure 4). The μ and σ values were determined by evaluating the depth of the largest roots using plants that were excavated immediately following our field investigations. This method reduced the noise in the first 0-10 cm bgs and enhanced visualization of the roots below that level. However, the signal from roots in the first 10 cm bgs was also reduced with this process.

Sample data gathered at one subplot during the final GPR data collection are shown in Figure 5. The raw GPR data (dewow and background subtraction applied) are shown for one profile (Figure 5a), which is highlighted in red on the depth slice in Figure 5b. This profile represents data gathered next to the cassava plants where roots are likely to be best imaged. Hyperbolae can be seen from the reflections of cassava roots in the subsurface; the vertices of these hyperbolae are marked by blue dots, and the locations can be seen in the depth slice 5b. This depth slice is centered at 0.225 m depth, and is indicated by the horizontal green box in 5a. It shows interpolated and processed data (dewow, gain, background subtract, migration, envelope) from the 36 GPR profiles in this subplot. The circle in 5b represents the typical horizontal extent of coarse root growth determined from excavated plants. It is also shown as a white box in 5a. The location of plants along the lines were recorded in the field and are shown as red diamonds in 5b.

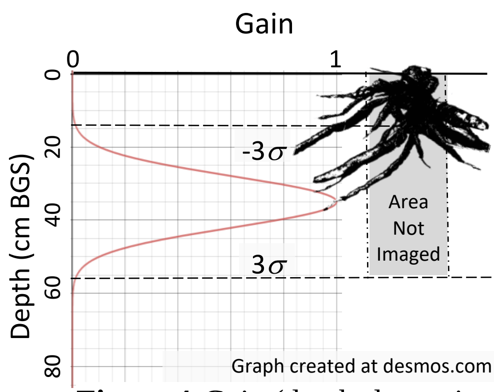

Figure 4: Gain (depth-determined) applied to the GPR data to accentuate data below 10cm BGS. Image of cassava roots scaled to size are shown next to the chart.

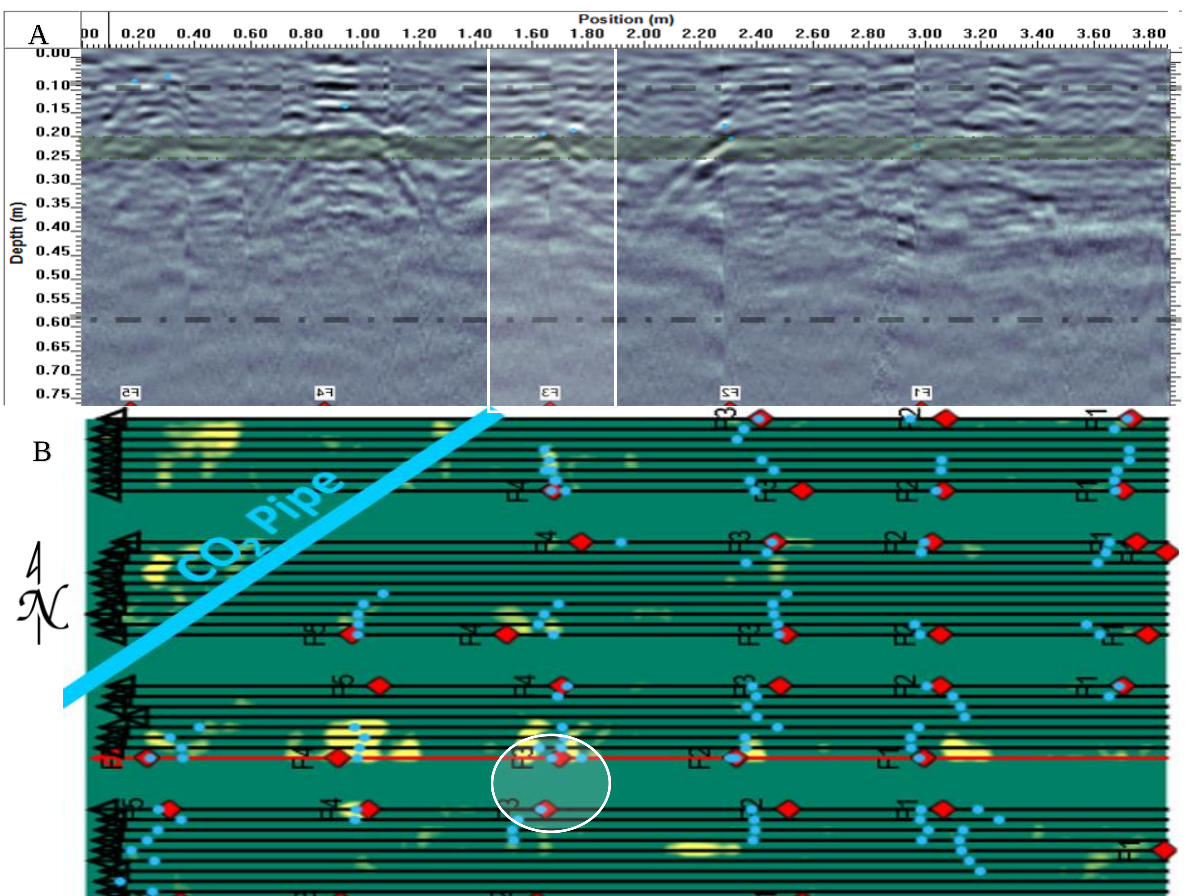

Figure 5: Partially processed GPR data that was gathered immediately prior to the third and final harvest of the season. A, a vertical section; B, a depth slice.

The GPR data were exported to Voxler for 3D analysis. Since most coarse root growth was contained within a 0.25 m radius of the stalk, we limited final analysis to data within that area (the radius for one plant is shown in Figure 6). With data constrained to these 0.25 m-radius spheres, isosurfaces were created to delineate roots. The green “blobs” in Figure 6 are the result. A scaled image of the excavated roots is shown next to that image to compare the imaged roots with excavated roots. The gray band down the center of the image shows areas not physically accessible to the GPR unit because of the cassava stalks. The imaged roots approximate the excavated roots. Other, non-root objects are evident just outside the edges of the circle, and a significant bulk of the roots are contained in the unmeasured area marked “Area Not Imaged.” However—though there are limitations—to the GPR images, there is correlation between the imaged roots and the roots that were excavated.

Figure 4: Top-down image of excavated roots next to a volumetric model of same roots.

Conclusions

We show qualitatively that the root biomass created by cassava plants in an elevated-CO_2 environment can be imaged non-destructively using GPR, and may be compared with other factors affecting plant growth while allowing the plant to continue to grow. The results could be improved with a denser network of GPR lines in multiple directions, a more precise planting protocol with greater distance between plants, a greater difference between permittivity of the matrix (soil) and the target (roots), denser time-series with more measurements per season, and a longer growing season where the roots are able to mature and grow larger. However, we show that GPR may be used effectively to image the growth of cassava and similar roots.

References

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