

# Imaging Tree Root Zone Geometry Using Electrical Resistivity Tomography

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**ABSTRACT** Root zone geometry research is usually done in a conventional way which is destructive, time-consuming, and requires a considerable cost. Several non-destructive measurements used geophysical methods have been developed, one of which is the Electrical Resistivity Tomography (ERT) method. Tree root zone determination using ERT has been carried out in Kiara Payung area, Sumedang, West Java, with *Maesopsis eminii* tree as the object study. A total of 29 ERT lines were measured using dipole-dipole configuration with electrodes spacing of 50 cm. The results of two-dimensional (2D) and three-dimensional (3D) inversion modeling show that the ERT method has been successfully imaging the tree root zone. The root zone is characterized as 100-700  $\Omega\text{m}$  with an elliptical shape geometry of the root plate. The root radius is estimated to be 4-5 m from the stem, the root zone diameter reaches 8-9 m at the shallow soil surface and the root zone depth is approximately 2-2.5 m.

**Keywords:** electrical resistivity tomography (ERT), root zone, tree, *Maesopsis eminii*.

**ABSTRAK** Pencitraan geometri zona perakaran pohon menggunakan electrical resistivity tomography. Penelitian geometri zona perakaran biasa dilakukan dengan cara konvensional yang destruktif, memakan waktu, dan membutuhkan biaya yang tidak sedikit. Beberapa pengukuran non-destruktif menggunakan metode geofisika telah dikembangkan, salah satunya adalah metode Electrical Resistivity Tomography (ERT). Penentuan zona perakaran pohon menggunakan metode ERT telah dilakukan di daerah Kiara Payung, Sumedang, Jawa Barat, dengan pohon *Maesopsis eminii* sebagai objek studi. Sebanyak 29 lintasan ERT diukur menggunakan konfigurasi dipole-dipole pada dengan jarak antar elektroda 50 cm. Hasil pemodelan inversi dua dimensi (2D) dan tiga dimensi (3D) menunjukkan bahwa metode ERT telah berhasil mencitrakan zona perakaran pohon. Zona perakaran teridentifikasi berada pada nilai resistivitas 100-700  $\Omega\text{m}$  dengan root plate dan root cross-sections berbentuk elips. Radius akar diperkirakan sejauh 4-5 m dari pangkal batang, sedangkan diameter zona perakaran mencapai sekitar 8-9 m di permukaan tanah dangkal dan kedalaman zona perakaran diperkirakan antara ~2-2.5 m.

**Kata kunci:** electrical resistivity tomography (ERT), zona perakaran, pohon, *Maesopsis eminii*.

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## INTRODUCTION

Tree root is one of the most difficult organs to understand (Lazarovitch et al., 2018; Stover et al., 2007). However, it plays an important role and responsible for several functions in storage, synthesis of growth substances, sources of organic matter (Fitter, 2002), water and mineral nutrients absorption, and as an anchor to tree over-turning (Prieto et al., 2012). The root development process will directly change the soil structure and porosity and increase soil biomass production (Hultine et al., 2003).

The root zone geometry research is usually done with destructive measurement by soil excavation, monoliths, augers, trenching, etc., which is time-consuming, expensive, and challenging (Box, 1996), especially under large living trees (Pawlik dan Kasprzak, 2018). Several non-destructive methods have been developed, e.g. magnetic resonance, video and digital cameras (Box, 1996), glass walls, rhizotrons, minirhizotrons (Johnson et al., 2001), ground-penetrating radar (Al Hagrey, 2007; Hruska et al., 1999; Zenone et al., 2008), X-ray imaging (Pierret et al., 1999; Schmidt et al., 2012), seismic (Leucci, 2010; Weihs et al., 1999), and electrical resistivity (Ain-Lhout et al., 2016; Al Hagrey, 2007; Amato et al., 2008).

The electrical resistivity tomography (ERT) method has shown promising results. ERT is a fairly simple method, relatively inexpensive, easy to implement, and efficient for site investigation (Papadopoulos et al., 2007). This method has been trailed for rooting system research under the trees, herbaceous plants and gardens (Ain-Lhout et al., 2016; Amato et al., 2008; Corwin dan Lesch, 2005; Leucci, 2010; Michot et al., 2003; Morelli et al., 2007). ERT method also widely used to study soil moisture distribution, root zone geometry, wood decay, and stem anatomy (Al Hagrey, 2007; Michot et al., 2003). A close correlation between bulk resistivity and root mass density has been shown (Amato et al., 2008). However, to date it has not been able to image a single root in detail (Al Hagrey, 2007).

The root zone (rhizosphere) is an interface area between soil and vegetation which controls the movement of water, nutrients, and other commodities to the tree (Hinsinger et al., 2009; McNear, 2013). The tree root zone also changed the soil resistivity values (Al Hagrey and Petersen, 2011; Al Hagrey, 2007). Root density measurement is complicated and hard to obtain (Raats, 2007), thus geometrical information is needed both temporally and spatially under soil profile.

In Indonesia, the applications of ERT in root zone research is lacking in number. Therefore, the specific objective of this research is to conduct a preliminary study in determining the geometry of the tree root zone in 2D and 3D manner using the ERT method.

## LOCATION AND OBJECT STUDY

The study site is located in Kiara Payung, Sumedang, West Java, at an altitude of 925 m above sea level. It is situated at the southeastern flank of Mount Manglayang, a presumably Early to Middle Quaternary inactive (dormant) volcano (Dam et al., 1996). Manglayang and surrounding area was mapped to have been covered by undifferentiated young volcanic deposits consist of tuffaceous sand, lapilli, lava, and agglomerate (Alzwar et al., 1992). A recent study mapped the surrounding area to have formed by pyroclastic breccia-andesite enstatite lava and andesite enstatite lava rock units (Wiavianto et al., 2017). The study also revealed that the andesite lava of Manglayang was formed at a relatively lower temperature as compared to the basalt lava of Mount Palasari in the west and the andesite lava of Mount Pangparang in the north.

The weathering of this intermediary andesitic lava in Manglayang produces *Andisols* soil types with the soil family were *Typic Hapludands* (Soil and Agroclimatic Research Center, 1993; Soil Survey Staff, 2014). *Andisols* was volcanic soils which developed from young parent material (tuffaceous sand, lapilli, breccia, lava, and agglomerates) (Arifin dan Devnita, 2008).

The research object is tree species of *Maesopsis eminii*. The tree height is 14 m, stem diameter (DBH) 63.5 cm, and crown width 14.7 cm. The *Maesopsis eminii* tree grows at an altitude of 600 to 1.500 m above sea level with rainfall of 1.200 to 3.600 mm/year. The rural community planted this tree mainly for wood production, and as green belt trees. *Maesopsis eminii* was a deciduous tree, height reaching 45 m with free branches 2/3 in total height (Bramasto et al., 2015).

## METHODS

The basic principle of ERT is to measure the resistivity by injecting electric current (I) into the soil surface through two current electrodes and measuring the voltage difference ( $\Delta V$ ) through potential electrodes. The apparent resistivity ( $\rho$ ) was then calculated using the following equation:

$$\rho_a = K \frac{\Delta V}{I} \dots \dots \dots (Ohm) \quad (1)$$

with K is geometry factor that depends on the electrode configuration.

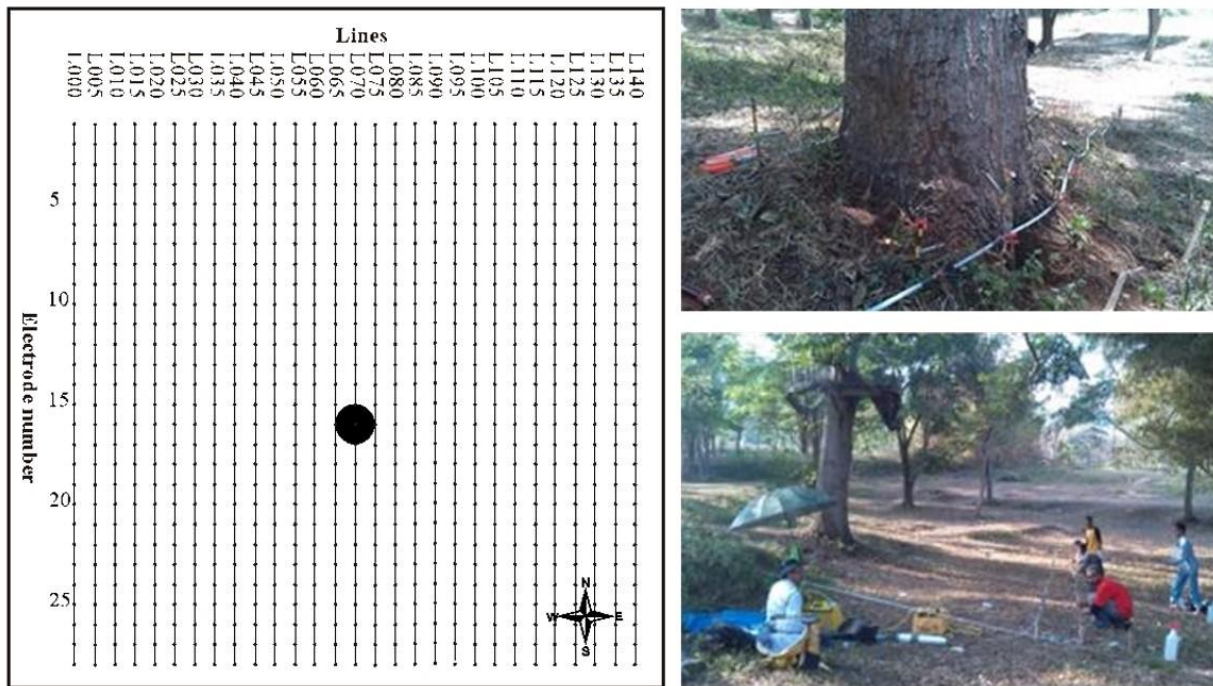


Figure 1. Schematic position of ERT measurements around the *Maesopsis eminii* tree.  
 (●: tree position; — ERT lines)

The ERT method was performed using Supersting R8/IP (Advance Geoscience Inc.) instrument. In the case of 3D resistivity imaging using multiple parallel 2D lines, the comparison between the inter-line distance and the electrode spacing will significantly influence the resulting inversion model (Okpoli, 2013). Furthermore, the author recommends that the interline distance should be the same as the electrode spacing (uniform grid). The uniform electrode distance in both lateral directions will result in higher sensitivity compared to the irregular grid. Taking into account the tree canopy width of about 14m, we designed a total of 29 lines with a 50 cm interline distance. Each line consists of 28 electrodes with a spacing of 50 cm and dipole-dipole electrode configuration was chosen (Figure 1). This array is very sensitive to the lateral resistivity variations, therefore it is very suitable to reconstruct a real model of the vertical three-dimensional structure with high resistivity values, such as roots and cavities (Leucci, 2010; Moreira et al., 2016). The line direction is in North-South direction and the *Maesopsis eminii* tree was on the 15th to 17th electrodes (L065-L075). Field observation was conducted in May 2017 (dry season). In this

preliminary result, we did not take into account the seasonal weather effect into the resistivity measurement.

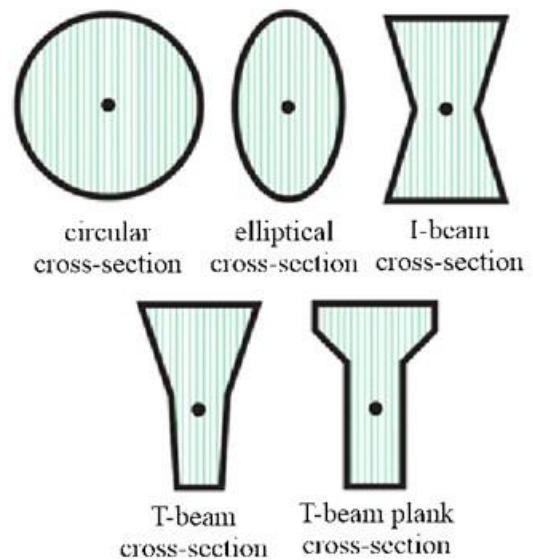


Figure 2. Illustration of root cross-sections shapes under tree stem (Coder, 2018).

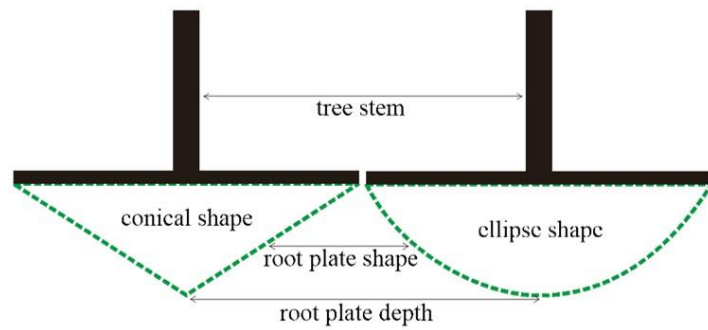


Figure 3. Side view illustration of root plate cross-sectional area under tree stem (Coder, 2018).

The acquired data were then processed in the mode of two-dimensional (2D) and three-dimensional (3D) inversion modeling using AGI EarthImager Inversion software. 2D and 3D

displays can provide an overview of the root cross-sections and depth of the root plate of the tree, as illustrated in Figures 2 and 3.

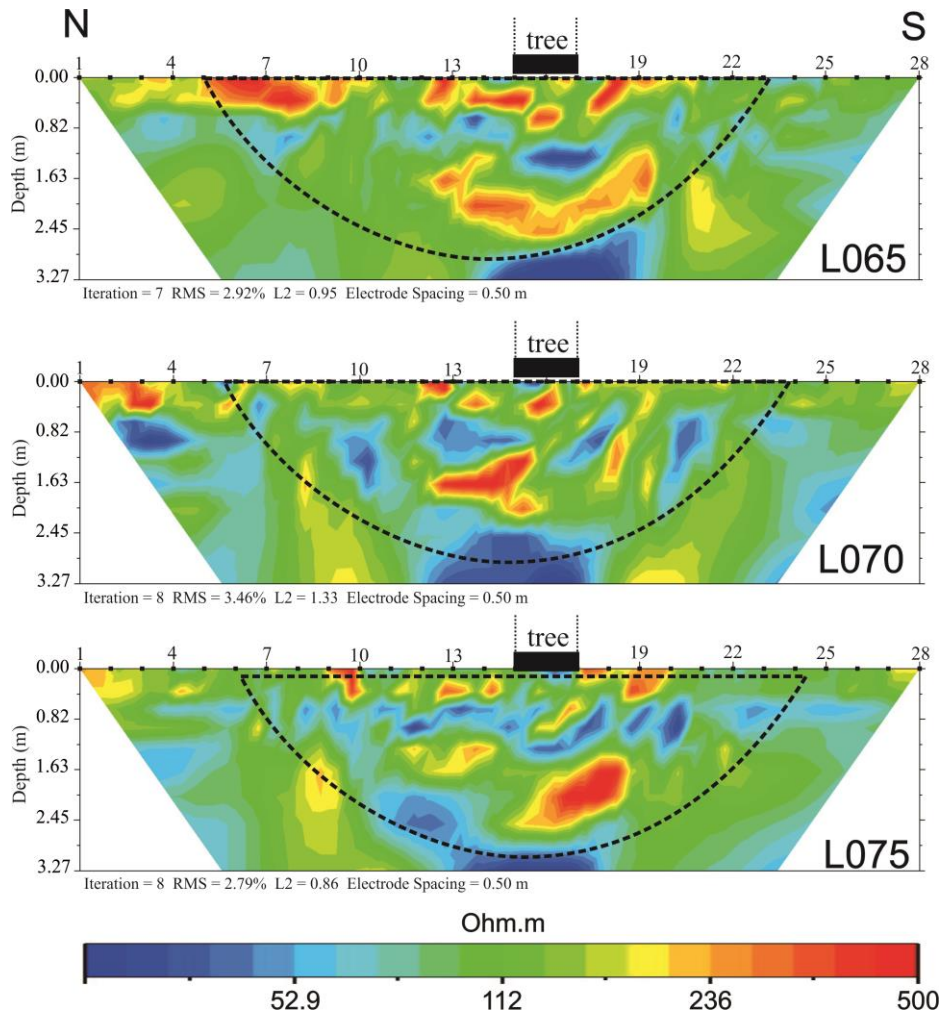


Figure 4. 2D inversion cross-section on three ERT line across the *Maesopsis eminii* tree. (■: tree position; ○: root plate cross-sectional area)

To compare the results obtained from the interpretation of the ERT model, root radius from the stem (Roering et al., 2003) and root plate depth (Coder, 2018) of the root zone are calculated using the stem diameter (DBH<sub>in</sub>) using these equations:

$$\text{Root radius from stem}_{\text{feet}} = 19.057 \times (0.0254 \times \text{DBH}_{\text{in}})^{0.59} \quad (2)$$

$$\text{Root plate depth}_{\text{feet}} = 0.3 \times \text{DBH}_{\text{in}} \quad (3)$$

## RESULTS AND DISCUSSION

### Two-Dimensional (2D) Inversion

In general, the result of 2D inversion shows high resistivity values (> 200 Ω.m) dominate the near-surface area (up to ~0.75 m). This high resistivity zones can be interpreted as the manifestation of dry soil and the presence of dense roots distribution. The low resistivity anomalies (<100 Ωm) that exist within the root zone (0.75-1.5 m) can be interpreted as a representation of soil layers with higher water content. High resistivity anomalies are also observed below the lower resistivity layer, in a more limited distribution.

As shown in Figure 4, the root radius from tree stem extends farther to the north rather than the south. The root distributed as far as 8.89 m at a depth of 0-0.75 m, characterized by resistivity values of 200-500 Ωm (yellow to red color zone). In Figure 4, the lateral resistivity changes likely illustrate the variations of root density which depends on the concentration of the nutrients in the soil surface layer (Leucci, 2010).

Figure 4 shows typical images from 2D inversion cross-section of three ERT lines, with the ellipse-shaped root plate cross-sectional area under *Maesopsis eminii* tree. The root plate depth is still observed to a depth of ~2.5 m depth (yellow color zone) in L065-L075 (Figure 4). The side view illustration of the root plate cross-sectional is shown in Figure 5.

### Three-Dimensional (3D) Inversion

Figure 6 is the result of 3D ERT inversion model, shown by horizontal resistivity slices in certain depths. In general, the result of 2D and 3D inversion share the same common features. The near-surface is dominated by the high resistivity anomaly (>200 Ω.m), followed by dominant low resistivity anomalies (<100 Ω.m) at a depth of

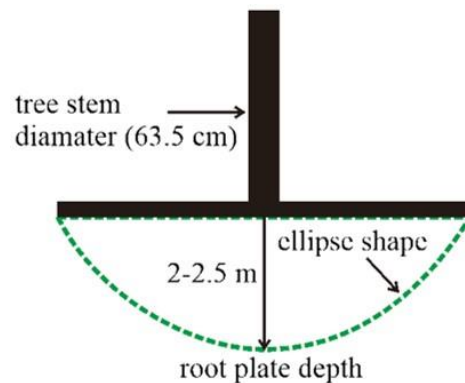


Figure 5. Illustration of tree root plate cross-sectional area under *Maesopsis eminii* tree.

about 0.75-1.5 m and medium to high resistivity values (100-300 Ω.m) in the lower part.

The root zone is characterized by the high resistivity anomaly, with a value of 200-700 Ωm. Similar results have been reported from resistivity measurements on eucalyptus trees in Lecce, Italy (Leucci, 2010) and pine and oak trees in Sierra San Miguelito Volcanic Complex, Mexico (Rodríguez-Robles et al., 2017). These authors characterize the tree root zone as a higher resistivity anomaly compared to the surrounding soil, excluding very high resistivity values of rocks.

The lateral root concentrated at depth of 0-0.75 m. The density of lateral root at ~0.25 m depth (Figure 6B) is greater than at the depths below (Figure 6C-D), and decreases sharply after depth of ~0.75 m. Root density (number of roots per unit volume) has a great abundance in the near-surface layer with mostly fine roots and decreases with depth (Leucci, 2010). Going deeper into the soil, smaller and less root density is present (Abernethy dan Rutherford, 2001; Tobin et al., 2007; Tosi, 2007).

The low resistivity (<100 Ωm) is increased dominantly at depth of 1.0-1.5 m (Figure 6E-G), due to the higher water content that obscures the low resistivity changes in the root zone. The medium to high resistivity anomaly is clearly still observed at depth of ~1.75- 2.5 m (Figure 6H-K), but the extent decreased following root plate depth. We interpret this as the tap root of the tree.

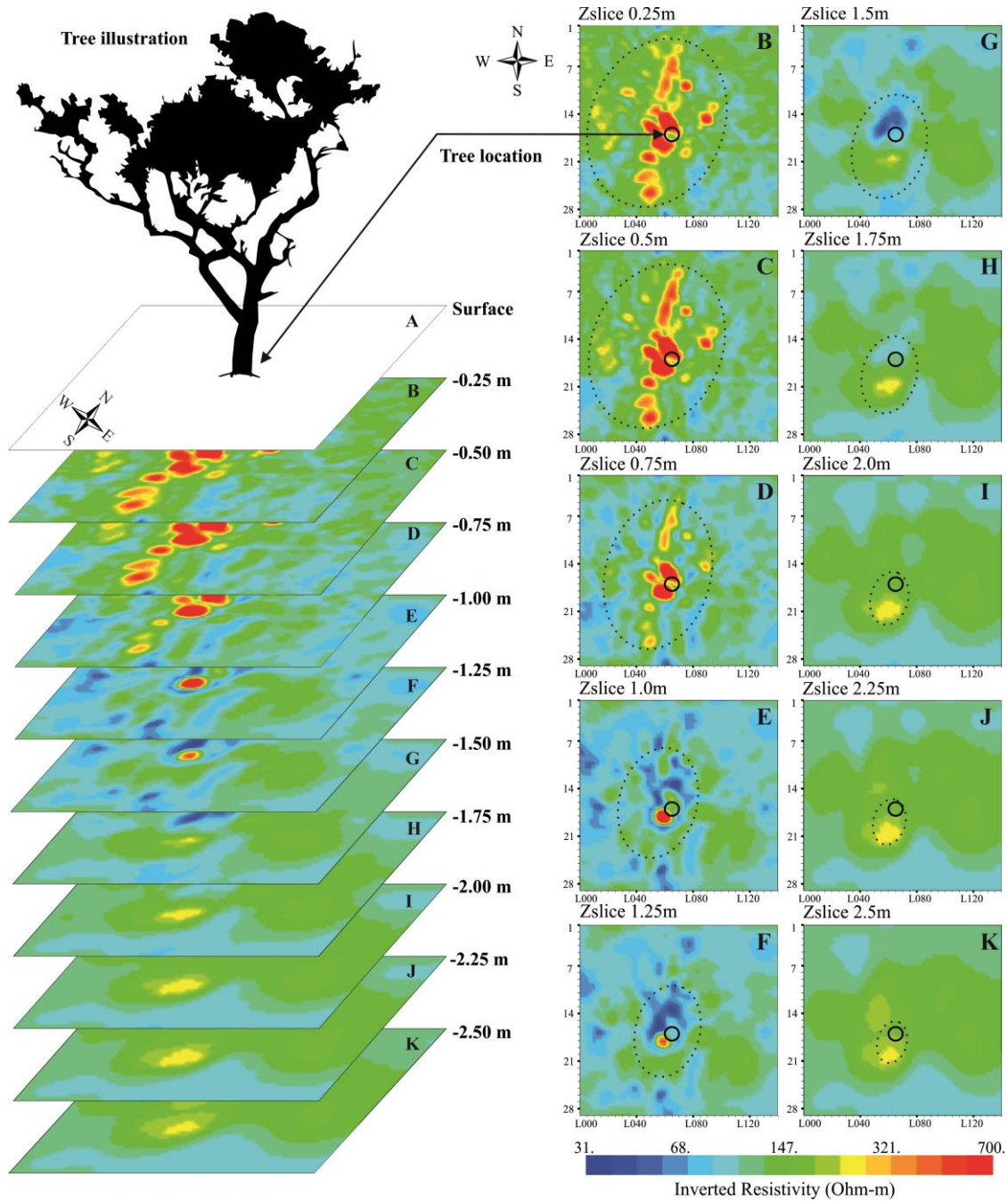


Figure 6. 3D inversion results at a depth of 0.25-2.5 meters sliced each 25 cm depth. (○: tree position; ○: root zone)

*Maesopsis eminii* was the tree species that have a dominant lateral root (root fibers) and tap-roots (Epila et al., 2017).

The 2D and 3D inversion resulted in a model slices with depth up to 3.25 m and 2.5 m respectively. The 3D model shows that the root zone is still observed at ~2.5 m depth, but the 2D

model shows that the root zone is not observed at the greater depth. This corresponds well with the estimates calculated from equation 3 (Coder, 2018), which yields an estimated value of ~2.29 m.

The spread of root growth is depends upon soil compaction which acting as a physical barrier to

root growth and by blocking oxygen movement to the root surface (Coder, 2018). Possibly the tree roots experience difficulties to physically penetrate the soil with a mass density greater than 1.7 g/cc (Coder, 2018).

Root radius from stem, based on equation 2, was 4.44 m, while the diameter of the root zone was 8.89 m. It is closely related to ERT result, which shows the radius of root approximately 4.5 to 5.0 m from the tree stem, while the diameter of the root zone was 7-9 m at shallow subsurface layers (~0.25-0.5 m). The 3D inversion shows the ellipse shape of the root zone (Figures 6B and H) and decreased sharply with depth.

Root zone is generally a consequence of relatively high moisture contents. However, only woody, thick and isolated roots are characterized by electric resistivity response, compared to the soil (Al Hagrey, 2007). The depth of root plate is limited by aerobic soil values (Peltola, 2006) and soil texture (Dupuy et al., 2007).

The root spreading direction (ellipse shape) is closely related to the crown shape of tree observation with north-south trending (Figure 7). Soil drainage, oxygenation, and carbon dioxide loss as impacted by soil texture, bulk density, and physical soil constraints affected root distribution in the soil (Bischetti et al., 2005).

## CONCLUSIONS

Electrical resistivity tomography (ERT) has been successfully imaged the root zone under the *Maesopsis eminii* tree. The root plate and root shape cross-sectional of the *Maesopsis eminii* tree has an elliptical shape. The resulted image corresponds well with the estimation calculated from the stem diameter. This ERT result has not been succeeded in imaging the root branching geometry in detail. However, we have shown that ERT is able to interpret the shape and depth of the tree root zone. Further study is needed to confirm this ERT result including time-lapse measurement to count the seasonal effect, the use of other geophysical methods, e.g. ground-penetrating radar (GPR), and/or direct method by trenching as validation.

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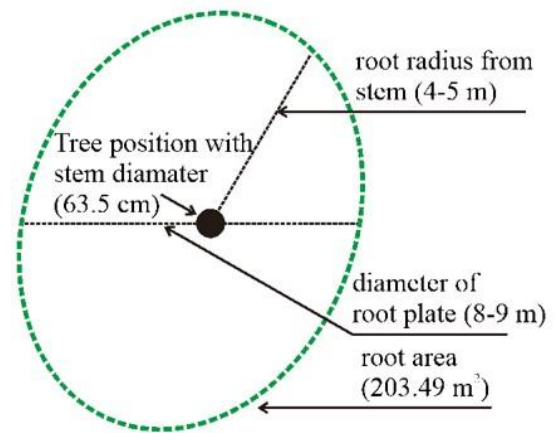


Figure 7. Illustration of ellipse cross-section shape of tree root by 3D inversion on depth 0-0.25 m.

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