Determining of Soil Resistivity by Electrical Resistivity Tomography in Agroforestry Land System

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Abstract. The study of soil hydrological characteristics is expensive and time-consuming due to its exercises drilling, test pit, and even trenching. The electrical resistivity tomography (ERT) technique is known as one of the viable methods for determining soil resistivity as a proxy for soil water content. The research has been done in three resistivity lines at the sloping agroforestry land system in West Java province-Indonesia. Soil resistivity value in the Pangalengan line transect ranges from 4.3-2500 Ω, Mandalahaji line transect ranges from 23-288 Ω, and Kiara Payung line transect ranges from 24-500 Ω. Soil resistivity under the agroforestry land system was higher than non-agroforestry land. Soil resistivity is firmly related to the soil water content with an inverse pattern. The use of woody tree species as a water absorber in the agroforestry farming system was the potential to prevent rapid soil saturation and maintain the stability of the steep area. In the steep area, the saturated condition decreases soil shear strength and increases the load on the upper slope so that it triggers soil mass movement.

1. Introduction

The agroforestry system combines the functions of forest trees and agricultural crops as a form of acculturation of environment and land system so that besides being able to contribute economically, it also has a positive impact on soil conservation [1,2]. The role of agroforestry with intercropping systems between timber woods, multipurpose trees, and horticulture can improve soil quality [3,4].

Basic information about soil properties is extremely vital in the agroforestry land system development. Soil aggregate (sand, silt, and clay) are closely related to soil hydrological characteristics, including the water holding capacity and soil hydraulics [5–7], cation exchange capacity [8], soil fertility [9], soil permeability, inhibit deep drainage, and potentially lead to soil inundated conditions [10]. The study of hydrological characteristics of the soil is time consumed and expensive due to its exercises drilling, test pit, and even trenching.

One method that's more viable in studying the soil hydrological characteristics is to utilize electrical resistivity tomography (ERT) techniques. This method has been widely applied in various scope, e.g., geological, geomorphological, and pedological research [11–13]. ERT has also been used in subsurface plant architecture, soil moisture, root zones, decaying wood zones, and stem anatomy [13–18]. ERT technique is based on physical subsurface properties (electrical properties of the soil/rock) measurement, as reflected by the soil/rock resistivity value. The electrical resistivity is a function of soil properties, as
particle size distribution, mineralogy, porosity, water content, solute concentration, temperature [13], and root biomass [19].

The woody tree species in agroforestry systems influence the soil hydrological conditions and are expected to reduce the level of soil saturation and increase the soil shear strength. Therefore, a soil hydrological description of the subsurface is needed. The purpose of this study was to determine the soil water in the agroforestry land system based on soil resistivity value.

2. Materials and Methods
The study area are located at three different locations at West Java province, Indonesia, i.e. (1) Pangalengan, (2) Mandalahaji, and (3) Kiarapayung, with elevation ranging from 920 to 1300 mean sea level (msl) (Figure 1).

The geomorphology of the study site (Table 1) is consisted of a hilly area and composed of volcanic products in Quarter age. The soil is predominantly formed by old volcanic rocks (Pangalengan and Mandalahaji), consisting of tuffaceous breccia containing pumice and old lava deposits with andesite, basal, and tuff [20]. The young volcanic rock products are located in the Kiarapayung site, consisting of tuffaceous sand, lapilli, breccia, lava, and agglomerates. The order soil types were Andisol in Pangalengan and Kiarapayung sites, while in the Mandalahaji is categorized as Inceptisols [21,22].

Table 1. Main features of the study sites

| Feature/locality | Pangalengan (Line 1) | Mandalahaji (Line 2) | Kiarapayung (Line 3) |
|------------------|----------------------|----------------------|----------------------|
| Geology          | Old volcanic rock (Qopu) | Guntur-Pangkalan-Kendang volcanic rock (Qqpk) | Young volcanic rock (Qyu) |
| Landform         | Middle volcanic slope | Old volcanic mountains | Upper volcanic slope |
| Parent material  | Andesite, Basalt dan Tuff | Breccia, Andesite dan Basalt | Andesite, Basalt dan Tuff |
| Soil type        | Andisols | Inceptisols | Andisols |
The quality of subsurface imaging with ERT techniques is influenced by the electrode configuration [23]. The electrode configuration used in this study is a dipole-dipole configuration (Figure 2). This configuration was chosen because it produces more datum data than other configurations, with a more detailed description of the hydrological conditions in the subsurface.

Figure 2. Illustration of the arrangement of dipole-dipole electrodes with a 56-electrode system

Superstring R8/IP with an 8-channel system (multi-channel) is used as the instrument for soil resistivity measurement. In this study, 56 electrode cables with placed every 50 cm intervals between electrodes were used to have a proper calibration of the depth of soil moisture. The electrodes line was carried out on two different sloping land systems, agroforestry, and non-agroforestry with a 45 m length. Data analysis and inversion modeling have been processed using AGI EarthImager 2D Inversion software. Data processing is done by 2D inversion with the target of <4% RMS misfit.

3. Results and Discussions

3.1. Pangalengan Line Transect
Pangalengan line transect consists of intercropping farming with *Eucalyptus deglupta* and *Raphanus raphanistrum* as an agroforestry land system, while non-agroforestry land is cultivated by *Sechium edule* (Figure 3). The results show a range of soil resistivity values varied from 4.3 to 2500 Ω in the subsurface of the Pangalengan line. Subsurface under the agroforestry land system has a soil resistivity value (in Ω or Ω) greater than 500 Ω, characterized by light yellow to red color. While under non-agroforestry land, the soil resistivity value is generally more homogeneous, with a value of less than 500 Ω (Figure 4).

In the agroforestry land system cultivated by *Eucalyptus deglupta*, the soil water content less dry than non-agroforestry trees. Typically, in understanding with the crop evapotranspiration of the Eucalyptus tree. Crop evapotranspiration level of *Eucalyptus pellita* in Riau-West Sumatera reached 73.1% [24], while the type of *Eucalyptus deglupta* in West Java was 52.9% [25].
Figure 3. (a) non-agroforestry land system cultivated by *Sechium edule*; (b) agroforestry land system with intercropping farming with *Eucalyptus deglupta* and *Raphanus raphanistrum*; (c) soil resistivity measurement illustration with 45 m electrode length; (d) resistivity line transect passing two land system illustration.
3.2. Mandalahaji Line Transect
The second line transect in Mandalahaji consists of *Gmelina arborea* trees with monoculture farming as an agroforestry land system and non-agroforestry cultivated by ex-corn (*Zea mays*) for comparison land (Figure 5).

![Figure 4. 2D spatial resistivity at Pangalengan line transect](image)

![Figure 5. (a) resistivity line transects passing two land system; (b) soil resistivity measurement with 45 m electrode length; (c) agroforestry land system cultivated by *Gmelina arborea* trees with monoculture farming illustration.](image)
The results show a range of soil resistivity values from 23-288 Ω in the subsurface of the Mandalahaji line (Figure 6). Subsurface under *Gmelina arborea* has a higher soil resistivity value compared to the non-agroforestry land system. Soil water content on agroforestry land tends to be drier characterized by soil resistivity values higher than 80 Ω. This is firmly related to the level of water absorption by the horizontal root distribution of agroforestry trees. Comprehensive studies of *Gmelina arborea* evapotranspiration level have not been widely carried out, but the range of evapotranspiration by referring to Teak trees (*Tectona grandis*) which are vegetation with the same family (Verbenaceae) reached 69.7% [26]. Morphologically, White Teak trees in this cultivation are still at a very young age (2 years). Therefore the vertical roots penetration rate may always not be exceptionally profound and even distributed at depths less than 1 meter below the surface.

![Figure 6. 2D spatial resistivity at Mandalahaji line transect](image)

### 3.3. Kiara Payung Line Transect

The third line transect of soil resistivity measurement in Kiara Payung comprises mixed woody tree species within the frame of *Swietenia macrophylla*, *Pterocarpus indicus*, and *Lagerstroemia speciosa*, whereas non-agroforestry land is within the shape of bare land with *Occonopus compressus* (Figure 7).

![Figure 7. Illustration of Kiara Payung line transect of soil resistivity with 45 m electrode length on two land system within agroforestry and non-agroforestry](image)

Soil resistivity values varied from 2.4-500 Ω in the subsurface of the Kiara Payung line. Soil resistivity value in the surface layer (0-0.3 m depth) smaller than 50 Ω for all land types, both agroforestry and non-agroforestry land systems. The differences occur at a depth of 0.3-1.0 m below the surface (Figure 8).
In Figure 8, the resistivity value under the perennial zone in Kiara Payung to 3 m depth is higher than 50 \( \Omega \). It’s firmly related to the deep root penetration rate of *Swietenia macrophylla* and *Pterocarpus indicus* so that the absorption of water in the soil becomes larger. Crop evapotranspiration of *Swietenia macrophylla* reached of 34.0\% [26]. The crop water need (crop evapotranspiration) is defined as the amount of water needed to meet the water loss through evapotranspiration or the amount of water required by crops to grow optimally, and it is influenced by the type, age, density and plant height [27].

The availability of water in the soil layer changed substantially over time and depends on rainfall intensity, soil hydraulic properties, and evapotranspiration [23]. Besides, the depth of plant root is one of the factors reducing the level of soil moisture. Plants root have many functions such as water pumps or hydraulic channels [28], which absorb water from the soil, which is used as photosynthetic process material. Roots are plant organs that actively absorb water. *Eucalyptus deglupta* and *Gmelina arborea* trees are known to have a deep taproot system. The rooting system of the *Gmelina arborea* is almost similar to the *Tectona grandis*, which has a deep taproot [29]. Trees with a tap root system can absorb water in a deeper layer [30].

The electrical resistivity decreases when the water content increases [13] (Figure 9). In saturated conditions, soil pore water pressure increases, and normal stress will reduce. In steep area will cause a decrease in soil shear strength and reduced soil stability. The horizontals roots that spread in the soil surface layer will grip the soil, and vertical roots (tap root) as anchors will support the uprightness of the tree, so it’s will stabilize the slope from mass movement [31]. Woody tree was the potential to maintain the stability of the sloping land with hydrological and mechanical (hydromechanical) functions [32]. The hydrological effect of the tree species on slope stability is to reduce soil water content through transpiration, interception, and evapotranspiration and the mechanical impact of vegetation to stabilize the slope through roots. Tree species is one of the natural technologies in reducing the occurrence of shallow soil mass movements during the rainy season [28,33].
Figure 9. Relationship between the electrical resistivity with volumetric water content [13]

Soil resistivity under the agroforestry land system was higher than non-agroforestry land. Soil resistivity firmly related to the soil water content with an inverse pattern. Resistivity zones associated with soil water content are influenced by plant roots distribution. The use of woody tree species in agroforestry farming system was potentially to maintain the stability of the steep area. It acts as a water absorber due to the contribution of plant roots.

Moreover, it prevents rapid soil saturation. In the steep area, the saturated condition decreases soil shear strength and increases the load on the upper slope, so that triggers soil mass movement. However, the application of soil resistivity for specific quantification of soil hydrological properties still needs further studies such as quantification of soil properties and root water uptake in various environmental conditions.

4. Conclusion

Soil resistivity value in the Pangalengan line transect ranges from 4.3-2500 Ω, Mandalahaji line transect ranges from 23-288 Ω, and Kiara Payung line transect ranges from 24-500 Ω. Soil resistivity under the agroforestry land system was higher than non-agroforestry land. Soil resistivity is firmly related to the soil water content with an inverse pattern. The use of woody tree species as a water absorber in the agroforestry farming system was the potential to prevents rapid soil saturation and maintain the stability of the steep area. In the steep area, the saturated condition decreases soil shear strength and increases the load on the upper slope so that it triggers soil mass movement.

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