Electrical Resistivity Tomography (ERT) of Immature Oil Palm Roots and Its Implication on Peanuts Growth and Yield in Intercropping for Sustainable Agriculture

Zainal Arifin[a,1,*], Eka Tarwaca Susila Putra[b]

[a] Department of Agribusiness, Vocational School Universitas Sebelas Maret, Indonesia
[b]Department of Agronomy, Faculty of Agriculture, Universitas Gadjah Mada, Indonesia
[1]Email: zainal.arifin@staff.uns.ac.id
*zainal.arifin@staff.uns.ac.id

Article history
Received : 15 February 2026
Revised : 20 February 2026
Accepted : 25 February 2026

Keywords
Elaeis guineensis, intercropping, root morphology, electrical resistivity, peanuts

ABSTRACT

This study aimed to determine the root distribution of three-year-old oil palms and the morphological characteristics of annual food crops grown under intercropping and monoculture systems. The research was conducted in Batu Penyu Village, East Belitung, using a single-factor *Randomized Complete Block Design* (RCBD) with three replications. The tested factor was the cropping system (intercropping vs. monoculture), with peanuts as the intercropped food crop. Oil palm root distribution was mapped non-destructively using electrical resistivity geoelectrical methods, while food crop root morphology was assessed destructively. Data were analyzed using Analysis of Variance (ANOVA), followed by a Least Significant Difference (LSD) test at a 5% significance level. 2D mapping of the oil palm root zone was processed using RES2DINV software. The results indicated that the root systems of three-year-old oil palms are dominated by primary and secondary roots, with minor contributions from tertiary and quaternary roots. These roots spread horizontally 1.5 – 2.5 m from the trunk at a depth of < 30 cm. This spatial arrangement suggests a lack of root zone competition between the oil palms and the intercropped food crops, as each species occupies distinct soil spaces. Furthermore, the root morphology of peanuts grown in the intercropping system was identical to those in monoculture, indicating that the growth and yield of intercropped peanuts are not inhibited by the presence of young oil palm roots.

1. Introduction

Electrical Resistivity Tomography (ERT) is a geophysical tool which can be utilised to study the soil and root electrical resistivity distribution, that has been widely used to assess subsurface attributes (soils and roots) [1]. This approach offers a powerful means of examining root system architecture, soil water status, and other belowground traits without damaging the plant. In agriculture research, ERT has recently offered a promising approach for investigating root-soil interactions that are crucial to achieve maximum crop growth and yield [1], [8], [10], [22]. In particular, the use of ERT in examining immature oil palm roots provides a unique tool for assessing root growth impact on intercropped peanuts.

Knowledge of these interactions can be advantageous for sustainable agricultural production in improving input use efficiency and growth performance of crops. The young oil palm, *Elaeis guineensis* is an important crop in tropical and subtropical countries being a major cash crop as well as a vehicle for global vegetable oil production [3]. These cropping systems in oil palm plantations, especially under intercropping with legumes (e.g., soybeans, peanuts), have been made to increase the land use efficiency and nutrient uptake for soil fertility [12], [15]. Nevertheless, little is known about the root dynamics and belowground competition between oil palm and peanut in the early growth of oil palm. The novelty in this study is that application of ERT to establish the spatial distribution and growth trends on immature oil palm root will provide insight into their effects on peanut roots development and hence crop performance. This information is important as it informs selection of intercropping systems which maximise complimentary and reduces competition between crop species [35].

The growth and yield of peanuts are affected by root interaction between interspecific plants and soil environments [4], [32]. In oil palm intercropping system, the competition for water, nutrients and space belowground might decrease legume access to critical resources and consequently influence on its physiological process and productivity [16], [35]. With ERT measuring the spatial and temporal dynamics of root biomass and soil moisture was tracked non-invasively [7], [27]. By combining ERT results with the ground truth obtained from peanuts growth parameters and yield components, researchers can explore more detailed mechanisms on how immature oil palm roots influence peanuts performance. This method aids in the establishment of management practices that lead to resource utilization efficiency and helps enhance sustainability of oil palm-peanuts intercropping systems [11], [34].

While the use of ERT for agricultural research is promising, its use to investigate immature oil palm root system and their effects on intercropped peanuts has been limited. Most studies have been conducted in mature oil palm or other crop species, resulting in a lack of information on early root growth and interspecific interactions when palms are grown together with the trees. The intention of this study is to fill in that gap using ERT for description immature oil-palm root distribution and extension on peanuts and its impact on growth and yield. This research is anticipated to deliver application-oriented recommendations for farmers, and agronomists who aim at increasing productivity and sustainability of cropping systems (oil palm and peanuts) contributing to food security improvement and environment conservation as well.

2. Method

This study shows that employing Electrical Resistivity Tomography (ERT) can provide improved means of resource conservation and intensified sustainability of oil palm-peanuts intercropping system. ERT studies are mainly carried out to determine mature oil palm roots or other crops, but little is known about young oil palm roots, and their impact when intercropped with peanuts. In this work we propose using ERT for studying the root zone patterns of immature oil palm and for evaluating how these roots influence peanuts growth and yield. The results will provide useful information for farmers and specialists to manage growth in these mixtures, ultimately increasing their productivity and environmental sustainability, that will guarantee food security on one hand and conservation on the other. The experiment was conducted in Batu Penyu Village, East Belitung by using a one-factor Randomized Complete Block Design (RCBD) with three repetitions for 4 months. The experiment was carried out in the succession system, comparing it to a sole crop where groundnut was used as intercrop in three-year-old oil palm rows. Control consisted of oil palm without intercrops, whereby the intra-row spacing were kept free from weeds and monoculture of *Arachis hypogea*. The distribution of oil palm roots was non-destructively mapped by geoelectrical methods based on electrical resistivity, whereas food crop root morphology was characterized destructively. Electrical Resistance Tomography (ERT) measures resistivity using two current electrodes to inject electricity (I) into the ground and potential electrodes to measure a potential difference (V). From these measurements, the apparent resistivity (p) is computed [2], [14]. Electrical resistivity is simple and economical, achieving an exploration of the subsurface by the passage of electric current. The resistivity measurements are following two lines within the rows of three-year-old oil palm [1], [8]. The following root characteristics of the peanut plant were determined in this study: dry weight (root and shoot), surface area, volume, total length, diameter (average diameter), specific gravity and root-to-shoot ratio. Reference parameters also consisted of plant height, leaf number, tiller number and total dry weight of the plant. The crop yield also played an important role. In addition, the following root growth parameters of a food crop grown were monitored; the ratios of absolute and relative lengths, surface area and volume of roots: duration for sum length, sum surface area and sum volume of the roots; average constriction rate mV–1 as well as RGR root. Data were analyzed using ANOVA, with LSD test at 5% probability. The 2D mapping of oil palm root zone was performed using the RES2DINV software.

3. Results and Discussion

3.1 Root zone mapping in intercropping system

The oil palm having its root zone in the ontercropping system with peanut is shown in Figure 1 that shows the lateral mapping of three year old oil palms intercropped with peanuts. The resistivity values have been classified in low (294–1221 Ohm m; blue to dark blue), medium (1221–1964 Ohm m; light green to dark green) and high (1964–8159 Ohm m, purple to yellow). The low resistivity values (294–1221 Ohm m) were therefore indicative for the prevalence of tertiary and quaternary roots, because lower resistivity is related to higher material conductivity. In particular, quaternary oil palm roots are characterized by having non-lignified white tissue; therefore they provide low level of resistance to electric current as shown by dark blue regions. In the primary and secondary root green zones resistance values are between 1221 and 1964 Ohm m.

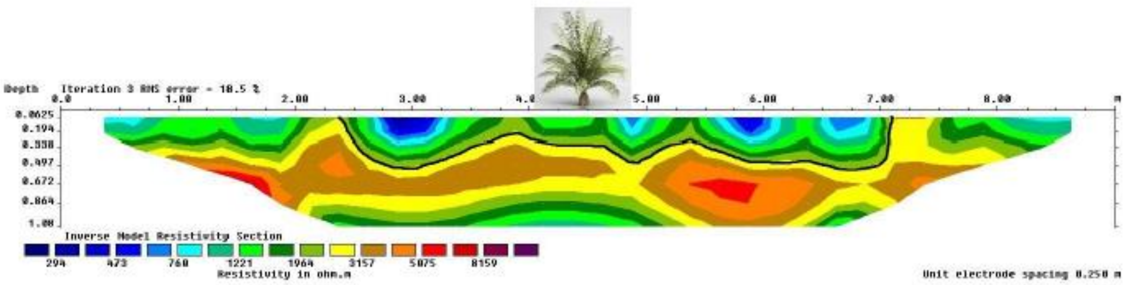

Fig. 1. 2D mapping cross section in oil palm intercropped with peanuts

Lower resistivity zones (blue regions) denote dominance of tertiary and quaternary roots. Oil palm quaternary roots are non-lignified and actively involved in water extraction, according to that; we could consider these features favouring by a higher electric conductivity than the soil medium among them. This finding corroborates the fact that Electro Resistivity Tomography (ERT) is highly sensitive of soil moisture content variance and the interest of active root biomass, and this enables non destructive spatial mapping of root distribution [1], [9]. The lack of continuity in the top soil layer (coordinates x=2 m to x=3.25 m) indicated a dense, mat-like root presence within intercropping systems. The effectiveness of ERT to identify such active zones is important for better understanding water uptake dynamics in the crop root zone [27].

3.2 Root zone mapping in monoculture system

Root zone of Oil palm monoculture system presented in Figure 2 shows the lateral resistivity profile for a three-year-old monoculture oil palm. Results show different resistivity levels, distributed in three values ranges: Low resistivity between 123 and 886 Ohm m (dark to light blue), medium between 886 and 1713 Ohm m (dark to light green) and high from 1713-12,377 Ohm m (yellow-purple). Low resistivity [(123–886 Ohm m)] is indicative of prevalence of tertiary and quaternary roots. Sometimes green areas are present on the primary and secondary roots. From the 2D mapping results, it can be seen that the order of colours is inversely proportional to variation in resistivity: blue (low real resistivity values) is used to represent peak value and more dark purple (high real resistivity values) as valley. This means that the upper layer contains a material of lower resistivity to injected current than underlying strata.

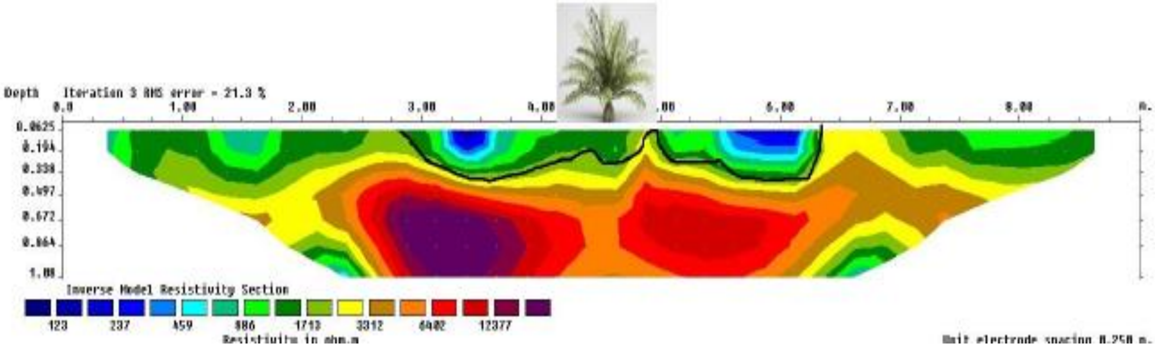

Fig. 2. 2D mapping cross section in oil palm monoculture

The variance of the root distribution discontinuity pattern is quite different for intercropping in comparison to monoculture. The intercropping system (with upland rice, corn, sorghum, soybean and peanuts) presents a resistivity discontinuity in the identifying upper layer for horizontal coordinates of x=2 m and x=3.25 m with oil palm being situated at position x=4.5m which represents tertiary and quaternary roots on the soil surface producing trampling resistant network at the topsoil. In comparison, the monoculture shows a discontinuity pattern ranging between x=2.5 m to x=2.75 m The distribution of the oil palm in the horizontal direction is 1.5–2.5 meters from the stem and approximately 0.3 meters below ground, such that all roots lie above 0.3 m of depth; primary and secondary roots are roughly confined to a depth interval from 0.3–0.5 meters (dark green for primaries, light green for secondaries) exhibiting medium-high resistivity as compared to tertiaries and quaternaries (blue). This phenomenon is being ascribed to the lignin content; quaternary roots are almost gui de void of series and thus exhibit resistivity values (dark blue) in the upper layer. Root zone (high moisture content) of the topsoil is outlined by black line, and the low-to-moderate resistivity contrast. soil resistivity around the roots is greater than soil resistivity inside the root zone. This is because the resistant of the root zone is lower due to higher moisture and more process for water and nutrient uptake. Low resistivity is attributed to high moisture in the rhizosphere and ion dissolution concentration. This demonstrates that, in principle, geophysical techniques can delineate root zones on the basis of associated conductivity contrasts relating to soil-root interactions and soil water status [10]. In addition, this map shows that the horizontal distribution of monoculture oil palm roots ranges between 1.5-2.5 m from the trunk base and up to 0.3 m in depth; such information is crucial to study root architecture nondestructively [20].

3.3 Root growth of Peanut (Arachis hypogea)

The root system of peanut (*Arachis hypogaea* L.) is characterized by a strong taproot with profuse lateral roots. The primary root can penetrate to a depth of 30-50 cm, and the root concentration is also distributed at an average depth of 5-25 cm. Siding is characterized by root nodules formed due to symbiosis with *Rhizobium* sp. Bacteria [5], [21], [28]. Resistance and adaptability of the *Arachis hypogea* root system to cropping patterns presented in Table 1 shows the resistance and adaptability of the *A. hypogea* root system when subjected to the various cropping regimes, focusing on how little influence intercropping has on changes in root physiological characteristics. The constancy within a limited range of the specific root length ratio (836.97-859.86 cm/g) implies that the biomass investment in roots remains efficient and steady, regardless of whether plants are cultivated in monoculture or in mixed with other crops. This indicates that the plants do not spend more resources for roots construction in an intercropping instead of root growth in a monoculture, which is the sign of trade-off relationship between root building and whole-plant growth. This steadfastness is important, as it indicates that intercropping does not essentially alter root morphology of the peanut plants just to compete for soil resources [6], [32].

Table 1. Root Growth Analysis of Peanut (*Arachis hypogea*)

Variables	Monoculture	Intercropping
Root length ratio (cm·g plant^{-1})	859,86 a	836,97 a
Root surface area ratio (cm^2·g plant^{-1})	127,42 a	103,61 a
Root volume ratio (cm^3·g plant^{-1})	3,76 a	1,94 a
Total root length duration (m·week)	26,96 a	29,24 a
Root surface area duration (cm^2·week)	210,08 a	207,59 a
Root volume duration (cm^3·week)	13,02 a	9,84 a
Root biomass duration (g·week)	6,94 a	8,44 a
Relative root growth rate (g·g^{-1}·week^{-1})	1,19 a	1,06 a

Note: Means followed by the same letter within a row indicate no significant difference based on the Least Significant Difference (LSD) test at $p < 0.05$

Moreover, the comparative values of relative root growth rate (1.06 vs. 1.19 g/g/week) and root biomass duration (8.44 vs. 6.94 g/week) further reinforce the conclusion that intercropping does not negatively influence below-ground dynamics. The slightly higher root growth rate in the monoculture is not statistically significant, which means that the metabolic activity and nutrient uptake capacity of peanut roots remain robust under intercropping conditions. This steady root performance is vital for sustaining nutrient acquisition and supporting above-ground growth, indicating that the below-ground competition typically expected in mixed cropping systems is either minimal or effectively mitigated [4], [36]. Overall, these findings underscore the potential of intercropping systems to maintain peanut root health and function without compromising physiological efficiency or growth duration.

3.4 Root Morphology and Agronomy characteristic of Peanut (Arachis hypogea)

In peanuts, the lateral roots initiate early, simultaneous with shoot elongation leading to development of an extensive root system [29], [30]. The dynamic development and stable agronomic performance of Arachis hypogea are illustrated in Table 2 for the monocrop system and intercropping system after these critical early growth stages (at 4 and 8 WAP). The result indicates that root biomass accumulation develops very well in both systems, and the root dry weight increases almost four times, presenting the intercropping system does not negatively influence on root growth. Moreover, the persistence of root system structure parameters (diameter and density) in the intercropping pattern indicates the crop's capacity to maintain necessary root architecture, which is important for nutrient and water acquisition [17], [25], [26].

Table 2. Morphology and Agronomy Perform of Peanut (*Arachis hypogea*)

Variables	Monoculture	Intercropping
Root dry weight (g) 4 WAP	1.10 a	1.07 a
Root dry weight (g) 8 WAP	4.07 a	4.08 a
Root surface area (cm^2) 4 WAP	55.32 a	42.48 a
Root surface area (cm^2) 8 WAP	301.17 a	345 a
Root volume (cm^3) 4 WAP	1.43 a	1.40 a
Root volume (cm^3) 8 WAP	3.13 a	3.73 a
Total root length (m) 4 WAP	0.18	0.19
Total root length (m) 8 WAP	4.86	4.62
Root diameter (cm) 4 WAP	0.12 a	0.11 a
Root diameter (cm) 8 WAP	0.20 a	0.15 a
Root density (g/cm^3) 4 WAP	0.87 a	0.70 a
Root density (g/cm^3) 8 WAP	1.30 a	1.12 a
Number of roots 4 WAP	27.72 a	26.28 a
Number of roots 8 WAP	44.17 a	43.44 a
Number of nodules 4 WAP	25.28 a	22.00 a
Number of nodules 8 WAP	9.70 a	8.33 a
Root/shoot ratio 4 WAP	0.99 a	0.61 a
Root/shoot ratio 8 WAP	0.54 a	0.53 a
Plant height (cm) 4 WAP	31.11 a	37.07 a
Plant height (cm) 8 WAP	44.17 a	47.40 a
Number of leaves 4 WAP	14.93 a	15.11 a
Number of leaves 8 WAP	33.87 a	24.44 a
Total dry weight (g) 4 WAP	2.33 a	1.95 a
Total dry weight (g) 8 WAP	11.94 a	9.73 a
Productivity (t/ha)	0.55 a	0.64 a

Note: Means followed by the same letter within a row indicate no significant difference based on the Least Significant Difference (LSD) test at $p < 0.05$

Notably, nodulation ability is a manifestation of the symbiotic process of nitrogen fixation and has not been influenced by intercropping condition [23], [24], implying that associate crop influence on beneficial rhizobial interactions for nitrogen acquisition and overall plant nutrition was not engaged in our case. Such a physical resilience can be also found at the individual level, as indicated by almost similar below/aboveground biomass allocation pattern (root/shoot ratio at 8 WAP) in both planting systems. Such a homeostasis in biomass partitioning contributes to sustained growth and resource use efficiency, leading to similar yield responses [18], [31]. The lack of a statistically significant yield benefit to the intercropping arrangement may suggest that *Arachis hypogea* is not susceptible to competitive stress or resource limitation. These results collectively support the plasticity and flexibility of the crop, allowing it to grow in different planting patterns without compromising functional root traits and agronomic performance. Their flexibility has relevance to agroecosystems, and intercropping can be used to improve land use without decreasing yield or crop health by this plant [19], [33]

4. Conclusion

This study employed Electrical Resistivity Tomography (ERT) to reveal that young oil palm roots are concentrated horizontally up to 2.5 m at depths of less than 30 cm, effectively minimizing below-ground competition with intercrops. Agronomic results confirmed the success of this system, demonstrating that peanut root growth and productivity in the intercropping system were comparable to monoculture, with no significant reduction in yield

Acknowledgment

The author thanks the DIKTI funding and Faculty of Agriculture, Universitas Gadjah Mada, for academic support and encouragement during the development of this manuscript. Sincere appreciation is also extended to peers and reviewers for valuable comments that strengthened the final version of the paper.

Data and Software Availability Statements

The data supporting this study are derived from primary data in field site. Citation management was performed using **Mendeley.**

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