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Morphological characters of root and yield of three cocoa (*Theobroma cacao* L.) clones in the field with dead-end trench

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ABSTRACT

Cocoa (*Theobroma cacao* L.) is a perennial crop originated from tropical regions, divided into Criollo, Forastero, and Trinitario. Demand for cocoa has increased, but the productivity is still low. The increase in production could be achieved by improving crop management and using superior clones. RCC-70, RCC-71, and KKM-22 are recommended as the superior cocoa clones. Dead-end trench can reduce erosion and surface run-off as well as improve rooting and soil organic matter sequestration. The objectives of this research were to study the effects of dead-end trench application on morphological characters of roots and yields of three cocoa clones and to determine which cocoa clone(s) performed a significant yield increase with the application of dead-end trench. The research was conducted in August 2018–April 2019 at Pagilaran Ltd. cocoa plantation in North Segayung Production Unit, subdistrict Tulis, Batang, Central Java. The experiment was arranged in a randomized complete block design with two factors and three replications as block. The first factor was dead-end trench application (with and without dead-end trench application) and the second factor was cocoa clones (RCC-70, RCC-71, and KKM-22). This study showed that application of dead-end trench and clones significantly increased root fresh weight, root dry weight, seed fresh weight, and seed dry weight, but had no significant effect on fruit diameter, fruit length, root length, and root surface area. RCC-70 clone, coupled with the application of dead-end trench, resulted in the highest seed dry weight compared to RCC-71 and KKM-22 clones.

INTRODUCTION

Cacao is divided into Criollo, Forastero, and Trinitario types. According to its commercial aspect, there are two types of *T. cacao* L., consisting of Criollo (original) that has high quality properties and Forastero type that has low quality (Wood, 1985). Cocoa exports are still below its trade potential and can still be increased, especially cocoa butter to China, the Netherlands, and Japan (Suryana et al., 2014). Cocoa productivity is improved to meet the increasing market demand.

The average productivity of cocoa plantations in Indonesia, according to Ministry of Agriculture (2017) is 982 kg.ha^{-1}. Cocoa productivity in Indonesia is lower than its potential yield of > 2 tons.ha^{-1} (Amos and Thomson, 2015). The superior clones of cocoa recommended by coffee and cocoa research center (Puslitkoka) are RCC-70, RCC-71, and KKM-22 clones that have high productivity and resistance to pests and diseases. The high productivity is 2,287 kg.ha^{-1}, 2,284 kg.ha^{-1}, and 2.42 kg.ha^{-1}, respetively (Rajoniati, 2006). Superior clone use must be balanced with optimum environment and good management to support various plant organs growth and development.

Root is a plant organ, composed by stele, xylem, phloem, perisicles, endodermis, cortex, and epidermis. The roots developing below the soil surface is very important for plants (Putra et al., 2016). Apical dominance of roots can be removed by cutting plant roots to stimulate new roots establishment that are more effective for nutrients absorption. The dead-end trench application increases groundwater storage capacity. Oil palm plants show an increase in production with the treatment of mounds and dead-end trench, showing an increase in groundwater reserves. Correlation between the production of fresh fruit bunch in 2007 and monthly groundwater reserves in 2006 was quite close as indicated by the correlation coefficient (r) of 0.70 (Murtilaksono et al., 2009). The dead-end trench increases fertilizer efficiency as some of the fertilizer nutrients leached along with the run-off return to the dead-end trench hole, thereby improving fertilizer efficiency. The 3-year observation on rubber plants showed that fertilizers application in the dead-end trench increased the content of available P, K, Mg and Ca in the soil by 4–29, 6–20, 4–13, and 3–4 times, respectively, compared to the content of available P, K, Mg and Ca in the fertilizer application outside the dead-end trench. The dead-end trench also has a positive influence on improving rubber plant growth and yield (Nugroho, 2017). The content of N.P.K in the land using dead-end trench was higher than that in the land without the dead-end trench in coffee plantations. The dead-end trench application produced 1047.61 $kg.ha^{-1}$ per year green beans, while the cultivation in land without dead-end trench only produced 683.89 $kg.ha^{-1}$ per year green beans. This result showed that dead-end trench increased the productivity of arabica coffee plants (Satibi et al., 2019).

Most of cocoa roots are lateral or horizontal roots that develop near the surface of the soil. Therefore, root cutting can be done by constructing the dead-end trench around the crop. Most of cocoa lateral roots grow at a depth of up to 30 cm, in which 56% grow at a depth of 0-10, 26% grow at a depth of 11–20 cm, 14% grow at a depth of 2–30 cm and only 4% grow at a depth of more than 30 cm from the ground surface (Setiyono, 2012). Root cutting can stimulate new roots growth because of the loss of apical dominance at the root tip. The formation of new roots from the cutting at the edges are expected to support leaves growth and higher yields.

The related studies about the effect of dead-end trench on oil palm plants showed that the dry weight of primary roots, secondary roots, and tertiary roots was greater when dead-end trench was applied at a depth of 0–15 cm. Conversely, at a depth of 15–30 cm and >30 cm, the dry weight of roots was not affected by the presence of the dead-end trench (Kurniawan et al., 2014). The dead-end trench on coffee plants stimulates the growth of new roots as well as intercepts and retains falling water, soil solution, and nutrients to be absorbed in the area around the roots of coffee plants (Yuliasmara, 2016). The efforts in reducing the nutrient loss are carried out through soil and water conservation such as the construction of the dead-end trench. Run off, erosion, and nutrient loss are reduced by increasing the distance between the dead-end trench (Pratiwi and Salim, 2013). Increased root development by constructing the dead-end trench will support plants to improve water absorption. Optimum water potential conditions in plants will support plant water uptake as well as increase nutrient uptake. Plants require many nutrients to support various physiological processes, such as photosynthesis, respiration, and transpiration. The photosynthesis process will produce dry material stored in the seeds. The cocoa yield is in the form of the dried cacao beans that are ready to be processed.

Thus, it is necessary to conduct a study that examines the effect of the dead-end trench on the morphological character of the root formed and its effect on several cocoa clones, namely RCC-70, RCC-71, and KKM-22. The objectives of this research were to study the effects of dead-end trench application on morphological characters of roots and yields of three cocoa clones (RCC-70, RCC-71, and KKM-22) and to determine cocoa clone(s) performing a significant yield increase with the application of dead-end trench.

MATERIALS AND METHODS

The study was conducted in August 2018–April 2019 at Pagilaran Ltd. cocoa plantation in North Segayung Production Unit, subdistrict Tulis, Batang, Central Java. The experiment was arranged in a randomized complete block design with two factors and three blocks as replications. The first factor was dead-end trench application (with and without dead-end trench application) and the second factor was cocoa clones (RCC-70, RCC-71, and KKM-22). Within each block, three cocoa (*T. cacao* L.) clones were used as samples with total number of 56

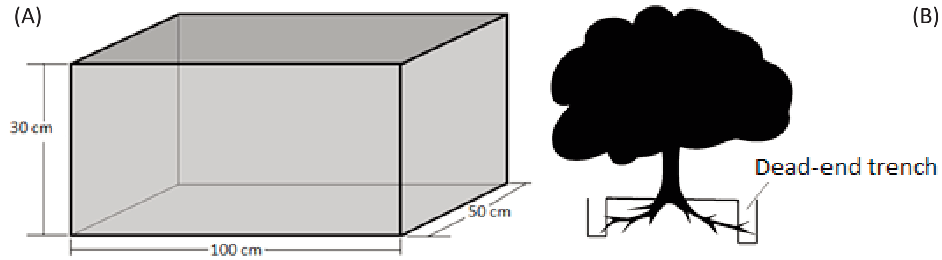

Figure 1. (A). Dead-end trench standard, (B). Dead-end trench layout

plants. The variables observed were soil conditions using the geoelectric resistivity method, root fresh weight, root dry weight, root length, root surface area, fruit diameter, fruit length, fruit fresh weight, fruit diameter, fruit length, seed fresh weight and seed dry weight.

The effect of the dead-end trench on active cocoa roots was detected by the geoelectric resistivity method. According to Wijaya (2015), the geoelectric resistivity is a method in geophysical science that explores the nature of electrical currents in the earth. This method develops detection from the surface of the earth including potential field, electrical current, and electromagnetic fields, both natural and artificial (earth current injection). In 1915, Wenner introduced configuration in geoelectric exploration. The arrangement distance of the Wenner configuration distance was the same spacing (r1= r4= a and r2= r3= 2a). Specifications of the equipment consist of Uninterruptible Power Supply device (APC BX1100LIMS), electrodes, voltage, and current measuring devices (Sanwa digital multitester CD800a made in Japan). Electrodes are made of iron with a diameter of 1 cm and a length of 20 cm. The electrodes were electrified, then current and voltage were read on the instrument.

Root morphology was observed by taking several samples. Ground drill was used to take soil samples at several points under the outer side of the canopy. Sampling was done once during the study. Root samples was taken at 15 points in a circle to represent root growth. The observation of the length, diameter, and surface area of the roots was made using area meter. The root fresh weight was weighed with digital scales, and the root dry weight was determined by storing the root samples in oven until a constant weight was obtained. The layout of the dead-end trench in the research is presented in Figure 1.

The data were analyzed using analysis of variance (ANOVA) with α = 5% and the Fisher's Least Significant Difference (LSD) with a level of α = 5% was then carried out. Data analysis was performed by using SAS 9.4 software. Geoelectric resistivity data analysis was performed by using Res2Dinv software.

RESULTS AND DISCUSSION

The minimum and maximum average temperature in the study area was 31.6°C and 34.2°C, respectively. Meanwhile, the minimum and maximum average humidity was 50.22% and 77%, consecutively.

The result of the observation of soil conditions using geoelectric resistivity method is shown in Figure 2. There are three parts in the figure; the first part shows the electrical resistivity distribution measured in the soil, the second part shows the apparent resistivity distribution based on calculations and the third part shows the resistivity distribution after the inversion shows the actual resistivity value. Variations in the distribution of ground water in the study area on track 1 and 2 indicated a change in the high, medium, and low resistivity values. High resistivity value was 2052–2301 Ωm (yellow to purple color), medium value was 1727–2052 Ωm (light green to dark green color), and low resistivity value was 1548–1727 Ωm (dark blue to light blue color) showed in Table 1. The depth of 0.625–0.319 m was dominated by blue color, it is indicating low resistivity. At the depth of 0.319–1.2 m, there were variations in resistivity from medium to high, which were indicated by a number of colors ranging between green and red. The inversion result (Figure 3) of track 2 obtained a high resistivity value between 2099–2346 Ωm, indicated by yellow to purple color. The resistivity value of 1776–2099 Ωm (light green to dark green color) was included in

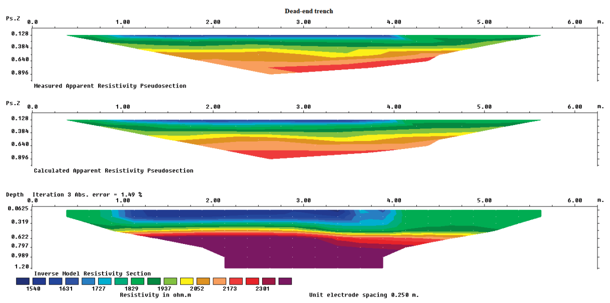

Figure 2. Track 1 with dead-end trench application

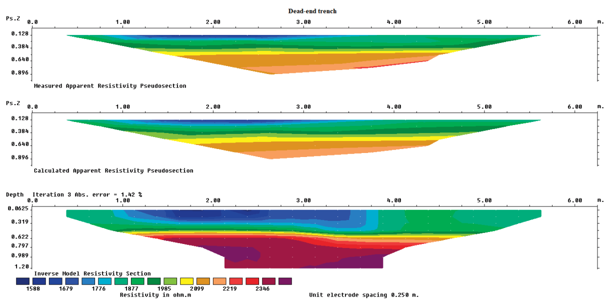

Figure 3. Track 2 with dead-end trench application

Table 1. Interpretation result of track 1 with dead-end trench application

No.	Contour color	Resistivity value
1.		1548 – 1727 Ωm
2.		1727 – 2052 Ωm
3.		2052 – 2301 Ωm

Table 2. Interpretation result of track 2 with dead-end trench application

No.	Contour color	Resistivity value
1.		1588 – 1776 Ωm
2.		1776 – 2099 Ωm
3.		2099 – 2346 Ωm

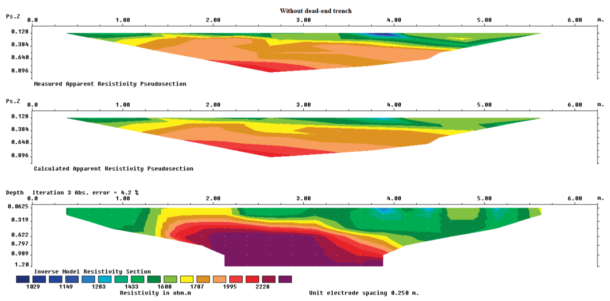

Figure 4. Track 1 without dead-end trench application

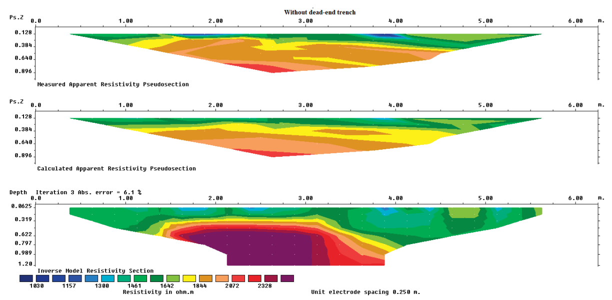

Figure 5. Track 2 without dead-end trench application

Table 3. Interpretation result of track 1 without dead-end trench application

No.	Contour color	Resistivity value
1.		1029 – 1283 Ωm
2.		1283 – 1787 Ωm
3.		1787 – 2228 Ωm

Table 4. Interpretation result of track 2 without dead-end trench application

No.	Contour color	Resistivity value
1.		1030 – 1300 Ωm
2.		1300 – 1848 Ωm
3.		1848 – 2328 Ωm

medium resistivity. Low resistivity was shown in dark blue to light blue color (1588–1776 Ωm) (Table 2).

The condition of soil without dead-end trench track 1 (Figure 4) observed using the geoelectric resistivity method showed a high resistivity value of 1787–2228 Ωm, showing the color of yellow to purple. The resistivity value of 1283–1787 Ωm (light green to dark green color) was included in medium resistivity. Meanwhile, the low resistivity (1029–1283 Ωm) was indicated by dark blue to light blue color (Table 3). The depth of 0.0625–0.319 m was dominated by green color, which indicated medium resistivity. At the depth of 0.319–1.2 m, there were variations in resistivity from medium to high, which was marked by a number of colors between green to red. In track 2 (Figure 5), the high resistivity value was between 1844–2328 Ωm, showing the color of yellow to purple. The resistivity value of 1300–1844 Ωm (light green to dark green color) was included in medium resistivity. Low resistivity (1030–1300 Ωm) was shown in dark blue to light blue color (Table 4). The depth of 0.0625–0.319 m was dominated by green color, which indicated medium resistivity. At the depth of 0.319–1.2 m, there were variations in resistivity from medium to high, indicated by a number of colors ranging between green and red.

The highest root fresh weight was shown by clone RCC-71 with dead-end trench treatment but it was not significantly different from the root fresh weight of clone KKM-22 with dead-end trench treatment and clone RCC-70 without dead-end trench treatment (Table 5). Meanwhile, the highest root dry weight was observed in clone RCC-71. Most of the plants with dead-end trench treatments produced higher number of roots. The presence of the dead-end trench had an effect on plant roots as evidenced by the higher root fresh and dry weight although there was no significant effect of the dead-end trench on the root length and root surface area.

There was no significant difference in the diameter and length of the fruit between treatments (Table 6), indicating that the clones and dead-end trench treatments did not have a significant effect on the fruit diameter and length. All clones with the dead-end trench treatment produced a higher seed fresh weight compared to the clones without the dead-end trench treatment. The highest seed fresh weight was shown by clone RCC-70 with the dead-end trench treatment, however, it was not significantly different from the seed fresh weight shown by clone RCC-71 with the same treatment.

Table 5. Root fresh weight, root dry weight, root length, root surface area

Treatments	Root length (cm)	Root surface area (mm)	Root fresh weight (g)	Root dry weight (g)
Clones				
RCC-70	4.77 a	1384.68 a	8.65 a	2.44 a
RCC-71	4.31 a	1658.43 a	9.05 a	2.36 a
KKM-22	4.05 a	2353.12 a	3.84 b	1.11 b
Dead-end Trench				
With	4.55 p	1830.67 p	8.91 p	2.09 p
Without	4.21 p	1765.48 p	5.45 q	1.84 p
Interaction	-	-	+	+
CV	29.69	22.98	38.317	6.94

Remarks: The value followed by the same letter in the same column showed no significant difference based on the LSD test at a significance level of α = 5%.

Table 6. Average fruit diameter, fruit length, seeds fresh weight, and seeds dry weight of three cocoa clones

Treatments	Fruit diameter (cm)	Fruit length (cm)	Seeds fresh weight (g)	Seeds dry weight (g)
Clones				
RCC-70	8.03 a	14.88 a	112.11 a	48.79 a
RCC-71	8.04 a	14.95 a	112.24 a	44.93 a
KKM-22	7.95 a	14.59 a	105.07 a	44.09 a
Dead-end Trench				
With	7.98 p	14.88 p	120.56 p	49.76 p
Without	8.03 p	14.73 p	99.05 p	42.11 p
Interaction	-	-	-	-
CV	3.66	5.96	8.91	10.54

Remarks: The value followed by the same letter in the same column showed no significant difference based on the LSD test at a significance level of α = 5%.

The dead-end trench in this research was a closed trench pit having various functions for water and soil conservation. The presence of the dead-end trench was expected to reduce surface runoff and erosion that can remove top soil (Pratiwi and Salim, 2013). Another impact of the dead-end trench made around the cocoa plantations was the cutting of roots so that there was new root regeneration. The formation of new roots makes the root system better at absorbing nutrients.

Resistivity measurement in this research was performed using geoelectric method. In 1912, Conrad Schlumberger was the first using geo-electric. The current injected to the ground in the geoelectric method is a DC (Direct Current) current. Variations in voltage differences cause variations in resistance, which are caused by differences in structure and material through which the electrical current is injected. The material in the soil has resistive properties so that there are differences in the electrical current conductance. The resistivity value obtained is influenced by the compactness of the material, porosity, and the presence of water in the soil. Measurement of resistivity is implied to be able to estimate the condition of cocoa roots in the soil. Investigation of resistivity does not damage the environment and low cost. Research shows that soil strength has a close relationship with soil resistivity (Simpen et al., 2018)

The surfaces of soil with the dead-end trench treatment were dominated by blue color, indicating the moist soil. The blue color was interpreted as the low resistivity part. High soil moisture at the top causes the movement of tertiary and quarterly roots (Nazari et al., 2015). The nutrient uptake by tertiary and quarterly roots is more active. Plants absorb nutrients and water in the form of electrically charged ions. Water or ions that are easier to conduct electricity will result in lower resistivity values.

The deeper soil had a higher resistivity value, indicating no ion decomposition. High resistivity was marked by the difficulty in conducting the electrical current due to the presence of resistivity in the form of soil material. The less water in the deeper soil also causes high resistivity. Cacao roams more on the surface, causing at least nutrients and water to be absorbed in these parts. Dry root penetration area causes no new root formation. The use of the dead-end trench causes more water stored in the soil supporting root growth. The root consists of various types that contribute to the structural and absorption functions. Deeper rooting allows plants to survive in drought conditions for maintained yields (Bianco and Kepinski, 2018).

Root extension, penetration depth, and root diameter are increased when the water content in the soil is sufficient. Roots can only develop once the conditions are suitable for their growth and development. The presence of the dead-end trench causes the soil to become more suitable for root growth due to the loss of mechanical resistance both in texture and structure that was less suitable. Tertiary and quarterly roots grew better in the presence of the dead-end trench, and the roots were found in parts of the soil with low resistivity. High resistivity values were dominated by primary and secondary root types. The primary roots keep the tree sturdy. The medium resistivity value was dominated by secondary roots but there were still primary roots. The resistivity measurement using geoelectric method conducted on oil palm plantations with Bio-Pore infiltration holes showed that the Bio-Pore holes given with organic material resulted in a lower resistivity value (Nazari, 2015).

The cocoa root system is assumed to contribute carbon (C) in a small portion of the total carbon stock in the cocoa agroecosystem. There is almost no direct root measurement of coarse root biomass because it is very risky for farmers. Root biomass is generally estimated using an allometric basis from a range of management conditions (Borden et al., 2017). The dead-end trench treatment allows the cutting of roots that trigger root regeneration. The roots of the cacao plant can reach a depth of 1.5–2 m, but the mass of the roots is located at a depth of 0.2–0.4 m, and spread laterally >5 m from the stem. Root characteristics are related to water availability, water content in plant, plant water use, and water productivity (Carr and Lockwoods, 2011). Most plants need an adequate and continuous supply of ground water and nutrients to grow, develop, and function normally. The roots act as vessels that help translocation and absorb moisture and nutrients from the soil to the nutritious and reproductive organs of plants (Wang et al., 2018). A study conducted by Kamga et al. (2018) showed that the treatment of root cutting in cocoa resulted in better roots at a lower auxin concentration. Excessive auxin in the root region slows down the stimulation of rhizogenesis. Root cutting in chrysanthemums is only 5% among the trigger of the new roots formation. The use of certain varieties gives a very maximum root growth in which the presence of certain hormone stimulators is not detected. However, the use of the IBA hormone gives a more compact rooting system (Cojocairu et al., 2018).

The higher crop management practice index to increase crop yields includes weed control, drainage treatment, fertilization, and application of pesticides to control disease, thereby allowing higher production (Dias-Jose et al., 2014). Provision of the dead-end trench in plantations is part of the efforts in plant management practices to provide a good environment for plants. These efforts do not directly affect plants on some of the observed physiological variables but rather to have a better impact on the yield of cocoa. RCC-70 with the dead-end trench treatment was seen to have the highest dry weight of seeds although it was not significantly different compared with clone RCC-71 with the dead-end trench treatment. The clones gave varied responses. The potential yield of RCC-70 was indeed higher than the potential yield of RCC-71 and KKM-22. Factors influencing the harvest index include energy and protein from seeds, long-term breeding program, and extreme temperatures (hot and cold) during the process of plant reproduction development. The relationships between local climate and harvest index can be used to temporarily and partially change the harvest index and to achieve the objective of plant breeding program in improving the practice of carbon accounting (Smith et al., 2018).

Young plantations in the good agricultural management practices require organic waste mulched on the soil surface. The the dead-end trench contains organic waste in the form of leaf litter accumulated in the dead-end trench hole. Organic waste, mulch, and cover crops help reduce water loss through intensive evaporation resulting in heat and sunlight insulation. This condition is the characteristic of tropical conditions associated with housing climate conditions (Ipinmoroti and Ogeh, 2014).

CONCLUSIONS

The use of the dead-end trench applied to the three tested cocoa clones, namely RCC-70, RCC-71, and KKM-22 significantly improved the morphological characteristics of the roots, increased root fresh weight, root dry weight, and seed dry weight. However, such improvements had not been expressed on yield components and yield of cocoa plants as indicated by variables of fresh fruit weight, fruit diameter, fruit length, and seed fresh weight.

REFERENCES

Amos, T. T. and O. A. Thomson. 2015. Climate change and the cocoa production in the tropical rain forest ecological zone of Ondo State, Nigeria. *Journal of Environment and Earth Science*, 5: 36–41.

Bianco, M.D. and S. Kepinski. 2018. Building a future with root architecture. *Journal of Experimental Botany*, 69: 5319–5323.

Borden, K. A., L. C. N. Anglaaere., S. Adu-Bredu., and M. E. Isaac. 2017. Root biomass variation of cocoa and implications for carbon stocks in agroforestry systems. *Springer Agroforestry System,* 93: 369–381.

Carr, M. K. V., and G. Lockwoods. 2011. The water relations and iirgation requirements of cocoa (*Theobroma cacao* L.) : a review. *Experimental Agriculture*, 47: 653–676.

Cojocairu, A., E. Chelariu., C. Tanase. 2018. Adventitious roots development and root system architecture of chrysanthemum cuttings. *Journal of Plant Development,* 25: 92–98.

Dias-Jose., O. Dias-Jose., S. Mora-Flores., R. Rendon-Medel, and R. Telles-Delgado. 2014. Cacao in Mexico : Restrictive factors and productivity levels. *Chilean Journal of Agricultural Research*, 74: 397–403.

Ipinmoroti, R.R., and J. S. Ogeh. 2014. Soil nutrient dynamic under old and young cocoa, coffee, and cashew plantation at Uhonmora, Edo State, Nigeria. *Journal Tropical Soil,* 19 : 85–90.

Kamga, K. M. D., D. T. Tchatchoua, R. G. Caspa, G. Y. A. Bessa, & L.J. Baleba. 2018. Rooting ability of cocoa (*Theobroma cacao* L.) stem cuttings: effect of genotype, cutting type, hormone concentration, and their interactions. *Asian Journal of Agricultural and Horticultural Research*, 1: 1–10.

Kurniawan, E. Ardian, and Wawan. 2014. Sifat kimia tanah dan perkembangan akar kelapa sawit (*Elaeis guineensis* Jacq.) pada berbagai dimensi rorak dengan pemberian tandan kosong. *Jom Faperta*, 1: 1–12.

Ministry of Agriculture. 2017. Statistik perkebunan Indonesia kakao 2015–2017. *https://drive.google.com/file/d/1sG27lYoxAtwrnFmlobgyAJdoVHv3YEb6/view.*

Murtilaksono, K., W. Darmosarkoro., E. S. Sutarta. H. H. Siregar., and Y. Hidayat. 2009. Upaya peningkatan produksi kelapa sawit melalui penerapan teknik konservasi tanah dan air. *Jurnal Tanah Tropika*, 1: 135–142.

Nazari, Y. A., Fakhrurrazie., N. Aidawati., and Gunawan. 2015. Deteksi perakaran kelapa sawit pada lubang biopori modifikasi dengan metode geolistrik resistivitas. *Ziraa'ah Majalah Ilmiah Pertanian*, 40: 31–39.

Nugroho, P. A. 2017. The study of silt pits establishment and empty fruit bunch application in rubber plantation. *Inovasi*, 14: 155–161.

Pratiwi and A. G. Salim. 2013. Aplikasi teknik konservasi tanah dengan sistem rorak pada tanaman Gmelina (*Gmelina arborea* Roxb.) di KHDTK Carita, Banten. *Jurnal Penelitian dan Konservasi Alam*, 10: 273–282.

Putra, D. R., B. Utomo., and A. Dalimunte. 2016. Morfologi perakaran tumbuhan monokotil DNA tumbuhan Dikotil. *Jurnal Universitas Sumatera Utara*, 5: 1–10.

Rajoniati. 2006. Pertumbuhan tunas sambung samping beberapa klon pada berbagai ketinggian batang utama tanaman kakao. Makassar: Sistem Pertanian Program Pascasarjana, Universitas Hasanuddin Makassar.

Satibi, M., Nasamsir., and Hayata. 2019. Pembuatan rorak pada perkebunan kopi Arabika (*Coffea arabica*) untuk meningkatkan produktivitas. *Jurnal Media Pertanian*, 4: 74–80.

Setiyono, R. T. 2012. Bahan tanaman unggul mendukung bioindustri kakao. *Balai Penelitian Tanaman Industri dan Penyegar*, 1: 3–11.

Simpen, I. N., N. P. G. B. Dewi., and I. N. Aribudiman. 2018. Relationship between resistivity and soil strength based on geoelectric data. *International Journal of Life Sciences,* 2: 22–29.

Smith, M. R., I. M. Rao, and A. Merchant. 2018. Source-sink relationships in crop plants and their influence on yield development and nutritional quality. *Frontiers in Plant Science*, 9: 1–6.

Suryana, A. T., A. Fariyanti, and A. Rifin. 2014. Analisis perdagangan kakao Indonesia di pasar internasional. *Jurnal Tanaman Industri dan Penyegar*, 1: 29–40.

Wang, X., J. Yun., P. Shi., Z. Li., P. Li., and Y. Xing. 2018. Root growth, fruit yield, and water use efficiency of greenhouse grown tomato under different irrigation regimes and nitrogen levels. *Journal of Plant Growth Regulation*, 38: 400–4.

Wijaya, A.S. 2015. Aplikasi metode geolistrik resistivitas konfigurasi Wenner untuk menentukan struktur tanah di halaman belakang SCC ITS Surabaya. *Jurnal Fisika Indonesia,* 55: 1–5.

Wood, G. A. R. 1985. *Cocoa*. 4^{th} ed. New York: Longman Inc.

Yuliasmara, F. 2016. Strategi mitigasi perkebunan kopi menghadapi perubahan iklim. *Warta Pusat Penelitian Kopi dan Kakao*, 28: 1–7.