GanoER TOMOGRAPHY FOR DETECTION OF EARLY DECAY IN OIL PALM TRUNK BY *Ganoderma* DISEASE

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Basal Stem Rot (BSR) disease caused by the white rot basidiomycete fungus, *Ganoderma* species, is a serious threat to the growth and production of oil palm, especially in Malaysia and Indonesia. The increase in BSR incidence over the past decade has attracted the attention of producers and researchers to carry out study on biology, early detection and disease control. Among the four different species of *Ganoderma* associated with BSR disease, *G. boninense* has been identified as the main causal agent of BSR disease (Idris, 2011). In Malaysia, the BSR disease was recorded on oil palm planted in Peninsular Malaysia (Idris *et al*., 2011 and 2017), Sabah (Walat and Hoong, 2011) and Sarawak (Rakib *et al*., 2014). Since 2000, MPOB has introduced the Integrated *Ganoderma* Management (IGM), which includes sanitation, biological and fertiliser formulation with beneficial nutrient elements as well as stump treatment with dazomet and fungicide hexaconazole (Idris *et al*., 2016a and b). Some existing BSR disease control methods and replanting management strategies have been achieved and are being implemented in several oil palm plantations and smallholders in Malaysia (Idris *et al*., 2011 and 2017).

The BSR disease is currently detected based on the development of foliar symptoms and the production of *Ganoderma* fructification in roots or trunk. There is an urgent need for more effective early detection of disease methods in order to quickly take remedial action (Idris *et al*., 2016a) to prevent transmission to healthy oil palms, leading to more diseases. Several methods for the ground and aerial detection of *Ganoderma* have been developed, through the culture-based techniques using *Ganoderma* selective medium (GSM) (Ariffin and Idris, 1992), molecular polymerase chain reaction-deoxyribonucleic acid (PCR-DNA), protein-based of the enzyme-linked immunosorbent assay-polyclonal antibody (ELISA-Pab) (Idris and Rafidah, 2008; Idris *et al*., 2003) and hyperspectral and radar remote sensing (Izzuddin *et al*., 2013). Non-destructive methods of examining the internal structure of the oil palm trunk are highly desirable, especially to confirm the diagnosis of internal early decay/rotting due to *Ganoderma* disease or damage by insect pests. It has been reported that tomography techniques for detecting wood decay or insect damage in palm trunks use ultrasound and stress waves (Lin *et al*., 2011), gamma rays (Abdullah *et al*., 2013), sonic waves (*e.g.* GanoSken tomography) (Idris *et al*., 2010), infrared heat (Al-Sulaiman and Hawwa, 2012), electrical impedance (Arango *et al*., 2016) and electrical resistance (ER) (Elliott *et al*., 2016). Application of ER tomography is relatively fast and non-destructive, therefore it is potential in estimating cross-sectional structure. ER tomography technique was investigated as a tool for diagnosing early decay/rotting caused by *Ganoderma* infection in oil palm. Baseline data is required for ER tomography as a useful tool. Preliminary results on detection of BSR disease in oil palm trunk trees using ER tomography was published (Nurnadiah *et al*., 2014).

TECHNOLOGY ON GanoER TOMOGRAPHY AND FIELD TESTING

The electrical resistance (ER, namely as GanoER) tomography was used to obtain oil palm trunk images at different stages of BSR disease development due to *Ganoderma* infection. This method uses pulsed electric current (DC, in ohm, Ω) to examine the tree properties that affect the resistivity of the oil palm wood. Properties such as water and moisture content, cell structure and ion concentration change if a decay in the tree is detected. A total of 24 mature oil palms planted in Setiawan, Perak (coastal soil, 26 years old of planting) were selected and divided into three groups: healthy (uninfected, T0, 8 palms), mild diseased (T1, 8 palms) and severe diseased (T2, 8

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palms). The data of ER values were collected using LandMapper ERM by inserting 16-nails (with 24 readings) into the oil palm trunk at three different heights from the soil levels (L0-10 to 15 cm, L1-30 to 35 cm and L2-60 to 65 cm). The nail was positioned at the stem trunk based on Wenner Array Principle (*Figure 1*). The minimum (min), maximum (max) and mean ER values were recorded and the data were interpolated using Kriging method to determine the decay/rotting areas in the oil palm trunk. All oil palm trees were felled and cross-sections (photograph by camera, *Figure 1*) were obtained to examine their internal decay/rotting and compared with the tomogram images (tomograph by GanoER tomography), with a total of 72 tomograms, 24 palms x 3 trunk heights from soil level obtained (*Figure 2*).

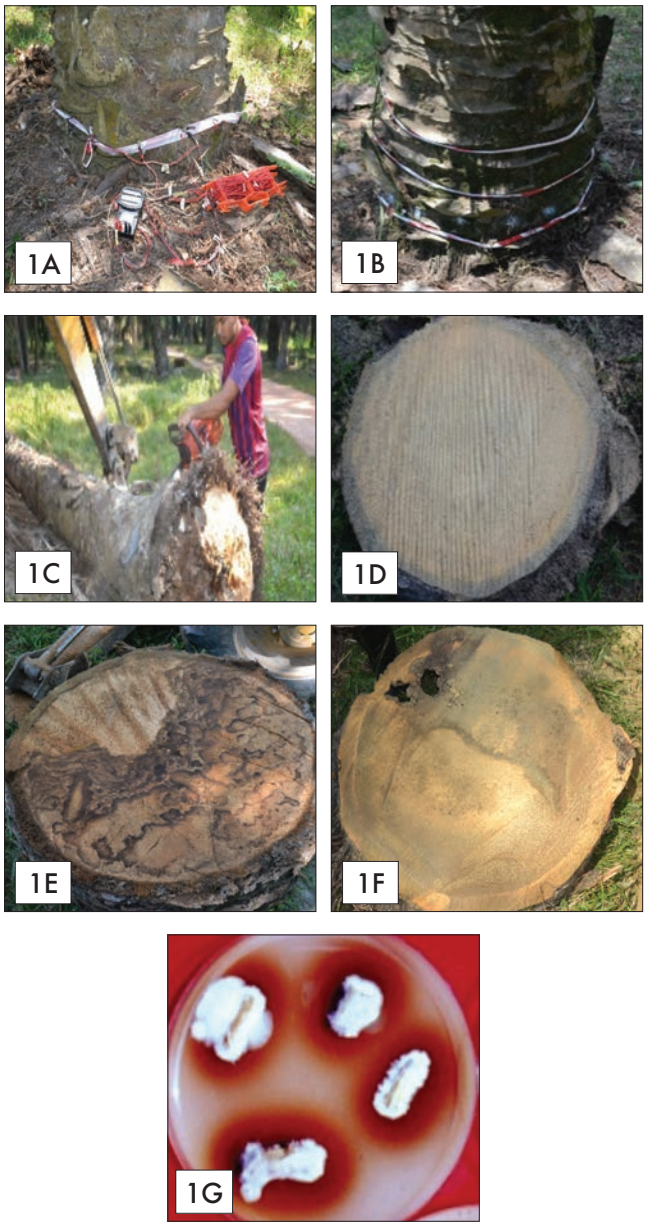

Figure 1. Installation of LandMapper ERM (1A) on oil palm stem trunk to record electrical resistance (ER) value (in ohm, Ω) at three different heights from the soil level (L0, L1 and L2; 1B). Palm was felled and cross-sections (1C) were obtained (photograph by camera) to examine internal decay (non-decay (0%), slightly decay (<30%), and moderate-severe decay (>30%); 1D, 1E and 1F)). The Ganoderma *selective medium (GSM) was used to confirm the presence of* Ganoderma *in roots or stem tissues (1G).*

In this study, the range of 1 to 50 Ω was used to represent the internal decay/rotting of oil palm trunk due to *Ganoderma* infection. The ER values (Ω) generated from a nail (emitter) and travels through an oil palm trunk to other nails (receptors) is called an ER line. The ER tomography was effective in illustrating the relative higher ER value of healthy oil palm trunk (uninfected, between 56.2 to 730 Ω) compared with slightly lower for mild diseased palms (between 6.5 to 598.0 Ω) and lower ER values for severe diseased (between 6.5 to 245.9 Ω), as the tomograms obtained from healthy oil palm trunk were distinctly different from the tomograms of the diseased oil palm trunks (presence decay/rotting). The ER tomography was also effective in visualising the internal decay/rotting oil palm trunk areas affected by *Ganoderma* fungus, as these decay/rotting areas had lower ER values (< 50 Ω).

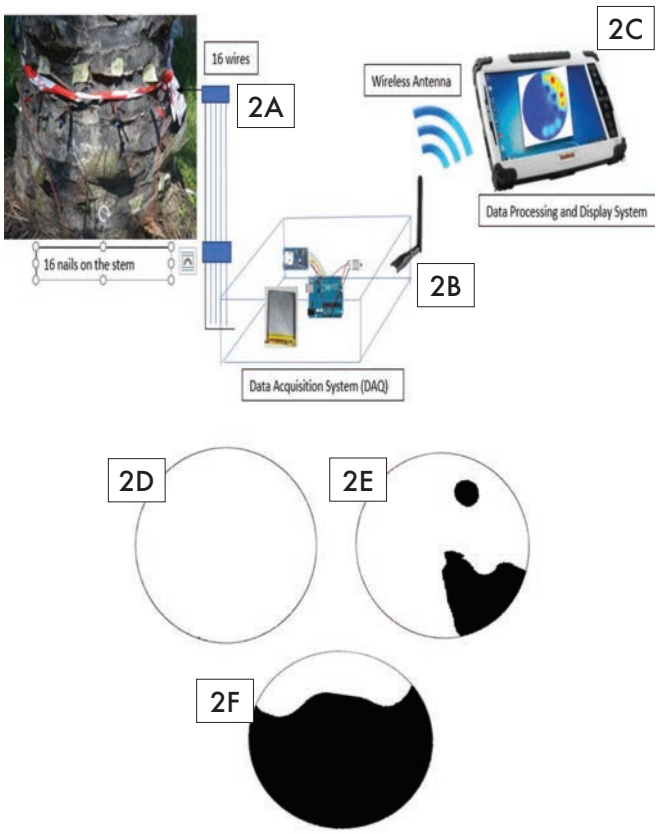

Figure 2. Data acquisition and processing of GanoER tomography (2A, 2B and 2C). Tomogram images of oil palm trunk with non-decay (0%), slightly decay (<30%) and severe decay (>30%) (2D, 2E and 2F). Black colour represents internal decay / rotting trunk (indicating low ER), while white colour represents non-decay / rotting of trunk (indicating high ER).

TABLE 1. RECOMMENDATION FOR CONTROL OF BASAL STEM ROT (BSR) DISEASE BASED ON PERCENTAGE (%) OF INTERNAL DECAY / ROTTING IN OIL PALM TRUNK USING GanoER TOMOGRAPHY

Decay/rotting in oil palm trunk using GanoER tomography (%)	Visual symptoms	Proposed action taken to control BSR disease in oil palm trees
0 (Healthy palm)	Oil palm tree with no foliar symptom, no fruiting body, no decay in trunk at the base, and palm producing fruit bunches.	Control as preventive treatment, *e.g.* biological agents or fertiliser formulation with beneficial nutrient elements.
1-30 (Mild diseased)	Oil palm tree with no foliar symptom but presence of fruiting body, no decay or slightly decay in trunk at the base, and palm producing fruit bunches.	Control as curative treatment or prolong life of infected palm, *e.g.* fungicide hexaconazole or soil mounding.
31-100 (Moderate-severe diseased)	Oil palm tree with foliar symptom, presence of fruiting body and decay in trunk at the base, and with or without producing fruit bunches.	Control as eradication treatment, *e.g.* sanitation by removal/destroy of infected palm using machine (backhoe/excavator) or stump/trunk treatment with dazomet or microbial degrader.

GanoER tomography images were produced and the size and site (location) of the *Ganoderma* infection in oil palm trunks were confirmed. The images of the REAL cross-sections (photograph by camera) were correlated with the tomography images (using GanoER tomography). White colour areas indicated non-decay or healthy trunks, while black colour areas indicated internal decay/rotting trunk due to *Ganoderma* infection. These inspections of the decay/rotting in oil palm trunks confirmed the infection of *Ganoderma* fungus using the *Ganoderma* selective medium (GSM), with presence as positive (+) and absence as negative (-) of *Ganoderma* isolation (*Figure 1*).

Based on the percentage of internal decay/rotting in oil palm trunk caused by *Ganoderma* infection (at 10-15 cm height from soil level (L0) using GanoER tomography, the recommendations for controlling BSR disease are presented in *Table 1*.

ECONOMIC ANALYSES

The estimated fixed cost of a customised complete device for the GanoER tomography system to detect internal decay/rotting in oil palm trunk infected by *Ganoderma* is about RM 880 960.00, which is based on the average volume of production of 80 units yr^{-1} for 5 years (*Table 2*). A unit of GanoER tomography is estimated to be RM 30 000.00 (device and software), which is cheaper compared with GanoSken tomography (RM 180 000.00) (Idris *et al*., 2010; MPOB TT No. 442).

TABLE 2. ECONOMIC ANALYSIS OF GanoER TOMOGRAPHY FOR DETECTION OF EARLY DECAY IN OIL PALM STEM TRUNK DUE TO *Ganoderma* DISEASE

Economic analysis	Value
Net present values (NPV) @ 10%, RM	4 554 426.00
Internal rate return (IRR), %	72.57
Discounted payback period, years	3
Discounted benefit: Cost (B:C Ratio)	2.02

CONCLUSION

GanoER tomography is a powerful tool for diagnosing (detecting) early internal decay/rotting of oil palm trunk due to BSR disease, which can be used to establish an early control and management programme through the Integrated *Ganoderma* Management (IGM). In both healthy (uninfected) and infected (mild and severe diseased) oil palm trunk by *Ganoderma* fungus, it was possible to calculate internal decay and non-decay stem tissues represented as a spectrum colour (black represents internal decay/rotting tissues or white represents

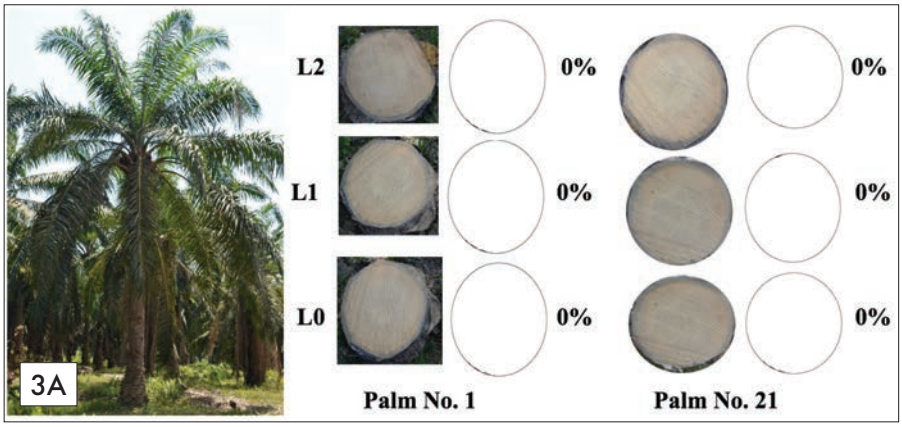

Figure 3. The healthy (uninfected, T0, 3A) palm without BSR foliar symptom, Ganoderma *fruiting body and root/ stem decay/ rotting at the stem base. Photograph (by camera) of oil palm trunk cross-section and tomogram images (ER values by GanoER tomography) at L0 (10-15 cm), L1 (30-35 cm) and L2 (60-65 cm), examples for palm No. 1 and No. 21 with no percentage (%) of internal decay. Black colour represents internal decay/ rotting trunk (indicating low ER), while white colour represents non-decay/ rotting trunk (indicating high ER).*

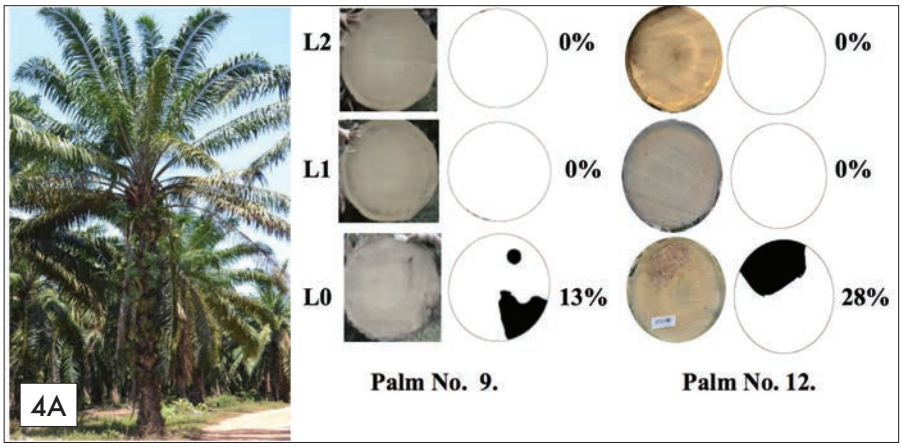

Figure 4. Mild diseased (T1; 4A) palm, no BSR foliar symptom, with Ganoderma *fruiting body and no or slightly decay at the stem base. Photograph (by camera) of oil palm trunk cross-section and tomograph (ER values, GanoER tomography) at L0 (10-15 cm), L1 (30-35 cm) and L2 (60-65 cm), examples for palm No. 9 and No. 12 with percentage (%) of internal decay. Black colour represents internal decay/ rotting trunk (indicating low ER), while white colour represents non-decay/ rotting trunk (indicating high ER).*

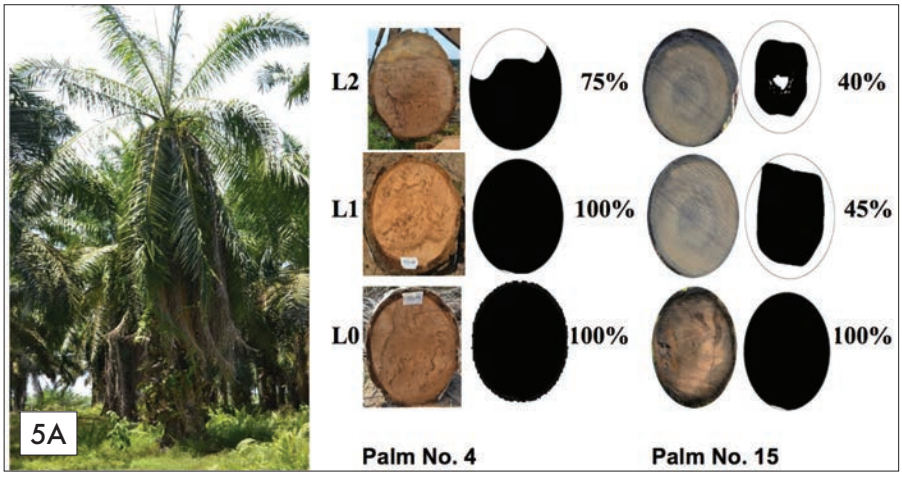

Figure 5. Severe diseased (T2, 5A) palm with BSR foliar symptom, Ganoderma *fruiting body and decay at the stem base. Photograph (by camera) and tomograph (ER values) of oil palm trunk cross-section at L0 (10-15 cm), L1 (30-35 cm) and L2 (60-65 cm), examples palm No. 4 and No. 15 with percentage (%) of internal decay. Black colour represents internal decay/ rotting trunk (indicating low ER), while white colour represents non-decay/ rotting trunk (indicating high ER).*

non-decay tissues). It was evident that some oil palm trees were in the earlier stages of *Ganoderma* infection, when others were in more advanced stages, affecting the ER measurement. Based on the ER values, the percentage (%) of internal trunk decay/rotting detected using GanoER tomography can be used to monitor the progress of decay/rotting in living standing oil palm trees. The ability to diagnose asymptomatic oil palm trees is a great advancement in disease management, not only will permit the reduction in *Ganoderma* inoculum by earlier eradication (by sanitation) of the affected oil palm trees, but also will provide researchers/managers with tools to evaluate earlier management practices such as fungicide treatment or removal of the infected oil palm. This will help to increase oil palm yield and productivity by reducing the losses due to *Ganoderma* disease.

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