PRELIMINARY STUDY ON DETECTION OF BASAL STEM ROT DISEASE AT OIL PALM TRUNK USING ELECTRICAL RESISTANCE

By

NURNADIAH BT ESA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
In Fulfilment of the Requirement for the
Degree of Master of Sciences

January 2016

FK 2016 79

Abstract of thesis presented to the Senate of the Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Master of Science

PRELIMINARY STUDY ON DETECTION OF BASAL STEM ROT DISEASE AT OIL PALM TRUNK USING ELECTRICAL RESISTANCE

By

NURNADIAH BT ESA

January 2016

Chairman: Aimrun Wayayok,PhD

Faculty: Engineering

Basal Stem Rot (BSR) disease is one of the most crucial diseases that attacks oil palm tree in Malaysia. It is caused by the wood-rotting fungus known as *Ganoderma boninense.* Early detection is important in managing BSR disease spreads as this disease wills ultimately results with the destruction of the basal tissues of the plant where it can lead to the decrease in the production of Fresh Fruit Bunch (FFB) yield. This study was conducted to detect BSR disease at oil palm tree by using electrical resistance (ER). Ten samples of trees at the age of 25 years were investigated. LandMapper ERM-2 was used in detecting the disease by collecting ER values at eight positions surrounding the trunk at three different heights (0 cm, 60 cm and 120 cm) based on Wenner array principle. Kriging was conducted to interpolate the ER values inside the trunk as well as to classify the level of severity, which were identified as T1 (non-infected), T2 (mild level) and T3 (moderate level). Classification technique of geometrical interval with 2 classes was used to differentiate between the decay and non-decay area .Spatial analysis was then performed to calculate and compared between two areas. Healthy positions give higher ER values of more than 30Ω while the infected positions give less than 30Ω. Moreover, healthy tree had a higher mean values than the infected tree. Destruction of the basal tissues and presence of fruiting bodies were only seen at the height of 0 cm in severity level T2 and T3. By using Kriging, interpolation of decayed area was approximately having the same position with the origin of the decay area captured by DSLR camera. Descriptive statistics for the infected tree at 0 cm showed that the highest mean was 50.54Ω which was at level T1 while levels T2 and T3 had mean of 30.80Ω and 29.25Ω respectively. For Duncan test, it only differentiates between healthy tree and infected tree due to small differences between levels T2 and T3. Therefore, this approach sounds to be feasible in detecting BSR disease to prevent the loss of the oil palm tree stands.

Abstrak tesis yang dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk penganugerahan Ijazah Master Sains

KAJIAN PERMULAAN BAGI PENGESANAN PENYAKIT REPUT PANGKAL BATANG PADA BATANG KELAPA SAWIT MENGGUNAKAN RINTANGAN ELEKTRIK

Oleh

NURNADIAH BT ESA

Januari 2016

Pengerusi: Aimrun Wayayok,PhD

Fakulti: Kejuruteraan

Penyakit Reput Pangkal Batang (RPB) adalah salah satu penyakit yang paling bahaya yang menyerang pokok kelapa sawit di Malaysia. Ia disebabkan oleh kulat kayu yang dikenali sebagai *Ganoderma boninense*. Pengesanan awal penyebaran penyakit ini adalah penting dalam menguruskan penyakit RPB kerana penyakit ini akan menyebabkan kemusnahan tisu pada pangkal batang dimana ia boleh membawa kepada penurunan hasil dalam pengeluaran Buah Tandan Segar (BTS). Kajian ini dijalankan untuk mengesan Penyakit Reput Pangkal Batang (RPB) pada pokok kelapa sawit dengan menggunakan rintangan eletrik (ER). Sepuluh sampel pokok termasuk pokok sihat dan sakit pada usia 25 tahun digunakan dalam kajian ini. LandMapper ERM-2 telah digunakan dalam mengesan penyakit ini dengan mengumpulkan nilai ER pada lapan kedudukan di sekeliling batang pokok pada tiga ketinggian yang berbeza (0 cm, 60 cm dan 120 cm) dengan menggunakan prinsip Wenner. 'Kriging' telah digunakan untuk membuat interpolasi nilai ER dalam batang serta mengklasifikasikan tahap penyakit yang telah dikenalpasti sebagai T1 (sihat), T2 (tahap sederhana) dan T3 (tahap pertengahan). Teknik pengelasan menggunakan selang geometri dengan 2 kelas telah digunakan untuk membezakan antara kawasan sihat dan kawasan pereputan. Analisis spatial kemudiannya dilakukan bagi mengira serta membandingkan keluasan antara dua kawasan. Kawasan yang sihat memberikan nilai ER lebih daripada 30Ω manakala kawasan yang dijangkiti memberikan nilai kurang daripada 30Ω. Selain itu, pokok yang sihat mempunyai nilai purata yang lebih tinggi berbanding pokok yang dijangkiti. Kemusnahan tisu pada pangkal batang dan kehadiran basidiomata hanya dapat dilihat pada ketinggian 0cm pada tahap penyakit T2 dan T3. Dengan menggunakan kaedah 'kriging', kedudukan interpolasi kawasan reput mempunyai kedudukan yang sama dengan gambar kawasan pereputan yang ditangkap menggunakan kamera DSLR. Statistik deskriptif untuk zon yang dijangkiti pada 0cm menunjukkan nilai purata tertinggi ialah 50.54Ω pada tahap T1 manakala T2 dan T3 mempunyai nilai purata 30.80Ω dan 29.25Ω. Untuk ujian Duncan, ia hanya dapat membezakan antara pokok sihat dan pokok yang dijangkiti disebabkan oleh perbezaan kecil di antara T2 dan T3. Pokok yang sihat mempunyai nilai ER lebih tinggi daripada yang dijangkiti. Kesimpulannya, pendekatan ini boleh digunakan dalam mengesan penyakit RPB bagi mengelakkan kehilangan pokok kelapa sawit.

ACKNOWLEDGEMENTS

Alhamdulillah, thanks to ALLAH for the immeasurable guidance, good health and direction for making all this possible in completing this study.

My sincerity gratitude goes to Dr.Aimrun Wayayok, the Chairman of my Supervisory Committee for his assistance, advice and guidance during the preparation of the thesis. I am also grateful to Dr.Idris Abu Seman and Dr.Muhammad Razif, the member of the Supervisory Committee for their invaluable assistance and guidance at the various stages of my research.

I am thankful to the Management of MPOB Kluang, Johor and Management of EPA Plantation under Kulim Plantation Berhad at Ulu Tiram, Johor for support and kindness in letting me to conduct my research at their plantation. I also owe to the En.Ezrin, En.Izzuddin and members of sampling team from Ganoderma and Research Department, Malaysian Palm Oil Board (MPOB) for their cooperation, guidance and time.

To my loving parent, Esa Ahmad and Zebedah Zain, my siblings and friends for their incalculable prayers and who always understand, motivate and encourages me to complete this study, I would like to express my full appreciation from deep of my heart to them.

Last but not least, thank you to Kementerian Pengajian Tinggi Malaysia and Universiti Putra Malaysia for giving me a financial support throughout scholarship during my study. May Allah bless all of us. Amin

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Aimrun Wayayok, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mhammad Razif Mahadi, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Idris Abu Seman, PhD
Head of Ganoderma and Disease Research Department for Oil Palm
Malaysian Palm Oil Board
(Member)

BUJANG KIM HUAT, PhD
Professor and Dean
School of Graduates Studies
Universiti Putra Malaysia

Date:

Declaration by Graduate Student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: _____

Name and Matric No.: NURNADIAH BT ESA

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of Chairman of Supervisory Committee:
Dr. Aimrun Wayayok

Signature: _____
Name of Member of Supervisory Committee
Dr. Muhammad Razif Mahadi

Signature: _____
Name of Member of Supervisory Committee
Dr. Idris Abu Seman

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

BSR	Basal Stem Rot
cm	Centimetre
DMRT	Duncan Multiple Range Test
DNA	Deoxyribonucleic acid
EC	Electrical Conductivity
ELISA	Enzyme linked Immunosorbent Assay-polyclonal antibody
ER	Electrical Resistance
ERT	Electrical Resistivity Tomography
FFB	Fresh Fruit Bunch
FTIR	Fourier Transform Infrared
GIS	Geographical Information System
GSM	Ganoderma Selective Medium
m	Meter
MPOB	Malaysian Palm Oil Board
PCR	Polymerase Chain Reaction
PIA	Pressure Injection Apparatus
%	percentage
Ω	Ohm

CHAPTER 1

INTRODUCTION

1.1 General Overview

Malaysia is the world's second largest producer of palm oil, which produced 18.79 million tonnes of crude palm oil (Pakiam, 2013). Although Indonesia is the main producer of palm oil, Malaysia still remain as the main exporter of this commodity with 18 million tonnes of palm oil products were exported in 2011 in satisfying the worldwide requirement for oils and fats. There are two main types of oils produced by oil palm namely palm oil and palm kernel oil. The productions of these products also face a challenge due to the infection of the diseases that cause reduction in the production of fresh fruit bunch (FFB).

Various research have been done to increase the FFB yield such as through the improvement in technologies and techniques of producing and harvesting FFB, improvement in soil fertility, overcoming the effect of the diseases as well as techniques in detecting the diseases that attack oil palm tree. Some of the most crucial disease that attack oil palm tree were vascular wilt caused by *Fusariam oxysporum* f.sp.*elaeidis,* basal stem rot caused by *Ganoderma* spp.,bud rot, red ring disease and sudden wilt (Turner,1981; Ariffin,2000; Martinez,2009).

From the crucial diseases that have been associated with oil palm tree, oil palm in South East Asia mainly Malaysia and Indonesia was infected by the Basal Stem Rot (BSR) disease. *Ganoderma boninense* is a wood-rotting fungus that caused BSR disease where it decreases the oil palm yield in most production areas. Turner (1981) had listed 15 species of Ganoderma from all over the world and out of seven species of Ganoderma was found in peninsular Malaysia. Besides that, Khairudin, (1990); Ho and Nawawi (1985) reported that *Ganoderma boninense* was the most perilous Ganoderma in peninsular Malaysia.

This disease will caused destruction of the basal tissues of the plant (Meor et al., 2009). *Ganoderma boninense* can be distinguished from other fungus as it has a double walled basidiospore with hard structure. Oil palm tree that been infected by BSR disease will have a severe problem in uptake of water and distribution of nutrient to the top part of the palm. It is due to infected xylem having degraded by the enzyme produced from this fungus (Idris et al., 2006).Besides that, BSR disease can caused up to 80% losses to the death of the affected palms.

It will also cause losses of FFB of the infected palm at the range of 25% to 45% (Idris et al., 2006). As a monocotyledonous crop, oil palm has both male and female inflorescence of the same plant. Lack of water uptake has causes the plant to produce more male inflorescences than the female. When there were appearance of fruiting bodies and foliar symptoms such as unopened spears, skirting of the fronds, and cavity at the trunks; oil palm tree was being diagnosed to be infected by this disease. At this stage, BSR had caused losses to the plantation.

Scientists have created several methods and instruments in distinguishing this infection. Some of the methods were Field Spectroscopy (Izzuddin et al., 2012), GanoSken Tomography (Idris et al., 2010), Ganoderma Selective Medium (GSM) (Ariffin et al., 1991), polymerase chain reaction-DNA (PCR-DNA) techniques (Idris et al., 2003) and enzyme-linked immunosorbent assay-polyclonal antibody (ELISA-PAb) (Idris and Rafidah, 2008). Detection of this disease at early stage is vital as it had been stated earlier that the standing palm with 20% infection can still be saved if it is properly treated (Meor et al., 2009).

Diagnosis tree vigour in standing tree using differential electrical resistance (ER) has been widely used especially in forestry. Two devices that being used ER principle were Shigometer and Resistograph (Shigo,1974; Moore, 1999; Paysen et al., 2001).

1.2 Problem Statement

Currently BSR could be recognized through the presence of the symptoms such as the appearance of fruiting bodies, wilting of the leaves and skirting of the fronds. Many researches have been carried out in order to detect the infection of BSR on the oil palm tree. As the symptoms of BSR disease could only be seen when the palm is already infected. Late detection has caused severe losses in terms of FFB harvested as well as the total loss of the palm stands in the infected area.

Technologies and tools were tested in order to detect the infection at the earlier stage. Lab analysis, imaging technology device, sound sensor and remote sensing had been tested in detecting BSR disease and there was some problems involve in terms of speed, ease of use and cost. Detection on BSR and factor surrounding the affected area could be a potential solution to overcome the losses and preventing the spread of the disease.

1.3 Purpose

The purpose of this research is to detect the Basal Stem Rot disease by using ER meter. This ER technique has not been tested in detecting this type of disease on oil palm but it has been used in detecting the tree vigour in forestry by using differential ER value. By knowing the ER differential value between healthy and infected palm, it will hopefully help in the prevention of the BSR disease as well as avoiding the losses of palm trees. Besides that, detection of BSR disease at any oil palm area could be a significant breakthrough to overcoming the consequences of the infection.

1.4 Objectives

The main objective of this research is to detect Basal Stem Rot (BSR) Disease by using Electrical Resistance (ER). The specific objectives are:-

- To determine ER values for healthy and infected oil palm tree by measuring the differential ER value at the palm trunk.
- To determine ER values for decay and non-decay area on each REAL image and interpolation to categorise the level of severity.

1.5 Scope and Limitation

This research was conducted at MPOB Kluang and Ladang Basir Ismail, Ulu Tiram, Johor. Ten oil palm trees at the age of 25 years old were used in this research in order to cut the tree. Cutting off the tree is important in this research for comparing the position of infected area with the interpolation method and also to determine the decay area as well as non-decay area. Besides that, soil type at this area was mineral soil with less than 5 degree slope.

1.6 Thesis Outline

The first Chapter will overview the introduction of oil palm and the negative impacts of BSR disease towards oil palms. It will then follow with a problem statement that pointed out the importance of this study in finding the solution. Literature review on causes of Basal Stem Rot and techniques that have been used in detecting the disease and decay in wood will be discussed in Chapter 2. Chapter 3 will be reporting the methods that have been used in this study. Result and discussions achieved from the studies was presented in Chapter 4 while conclusion and recommendation are reported in Chapter 5.

REFERENCES

Abdul Razak, J., Ahmad, H., Ramdhan, K., Idris, A., Abdul Rahim, S., and Aminul, R. (2004). Mechanical trunk injection for control of Ganoderma. *MPOB Information Series*.

Aimrun, W., Amin, M. S. M., Ahmad, D., Hanafi, M. M., and Chan, C.S. (2007). Spatial variability of bulk soil electrical conductivity in a Malaysian paddy field: key to soil management. *Paddy and Water Environment*, *5*(2), 113–121. doi:10.1007/s10333-007-0072-z

Ariffin, D., and Idris, A.S. (1991). A Selective Medium for the Isolation of Ganoderma from Diseased Tissues. *Proc. of the 1991 International Palm Oil Conference-Progress, Prospects & Challenges Towards the 21st Century(Model 1-Agriculture)(Yusof et.al.,eds).PORIM,*Bangi, p.571-519.

Ariffin, D. (2000). 'Status of Ganoderma in Oil 3 Palm'.In: Flood J.,Bridge P.D., Holderness M.,(eds) Ganoderma disease of pereenial crops. *CABI Publishing.Wallingford,*pp 49-68.

Ariffin, D., and Idris, A. (1992). Ganoderma selective medium (GSM). *PORIM Information series , (8)*.

Ariffin, D., Idris, A., and Marzuki, A. (1996). Spread of Ganoderma boninense and vegetative compatibility studies of a single field palm isolates. *In Proceedings of the 1996 PORIM International Palm Oil Congress (Agriculture)*, (pp. 317-329).

Ariffin, D., Idris, A., and Marzuki, A. (1995). Development of a technique to screen oil palm seedling for resistance to Gaoderma. *In Proc. 1995 PORIM National Palm Oil Conf*, pp. 132-141.

Ariffin, D., Singh, G., and Lim, T. (1989,September). Ganoderma in Malaysia-Current status and research strategy. *In Proceedings of the 1989 Palm Oil Research Institute Malaysia (PORIM) International Palm Oil Development Conference Module II: Agriculture*, (pp. 5-9).

Barker, R.D. (1989). Depth of Investigation of Collinear Symmetrical Four Electrode Arrays. *Geophysic*, 44:1031-1037.

Benjamin, M., and Chee, K. (1995). Basal stem rot of oil palm- a serious problem on inland soils. *MAPPS Newsletter,19(1):3*.

Bieker, D., Kehr, R., Weber, G., and Rust, S. (2010). Non-destructive monitoring of early stages of white rot by Trametes versicolor in Fraxinus excelsior. *Annals of Forest Science*, *67(2)*, 210. Retrieved from http://www.afs-journal.org/articles/forest/full_html/2010/02/f09220/f09220.html

Brazee, N.J., Marra, R.E., Gocke, L., and Van Wassenaer, P. (2010). Non-destructive assessment of internal decay in three hardwood species of northeastern North America using sonic and electrical impedance tomography. *Forestry*, *84*(1), 33–39. doi:10.1093/forestry/cpq040

Chong, K.P., Markus, A., and Rossall, S. (2012). The susceptibility of different varieties of oil palm seedlings to Ganoderma boninense infection. *Pakistan Journal of Botany*, *44*(6), pp 2001–2004. Retrieved from http://www.pakbs.org/pjbot/PDFs/44(6)/27.pdf

Corley, R.H.V., and Tinker, P.B., (2003). "The Oil Palm".4th Edition, *Blackwell Publishing, Oxford,U.K*.

Dayou, J., Alexander, A., Sipaut, C. S., Phin, C. K., and Chin, L.P. (2014). On The Possibility of Using FTIR for Detection of Ganoderma Boninense in Infected Oil Palm Tree, *International Journal of Advancesin Agricultural and Environment Engg. (IJAAEE)*, *1*(1), 10–12.

Deflorio, G., Fink, S., and Schwarze, F.W.M. R. (2008). Detection of incipient decay in tree stems with sonic tomography after wounding and fungal inoculation. *Wood Science and Technology*, *42*(2), 117–132. doi:10.1007/s00226-007-0159-0

Elliott, M.L., and Broschat, T.K. (2012). Ganoderma Butt Rot of Palms , University of Florida, Institute of Flood and agricultural Science,pg 1-7.

Eltaib, S. (2003). *Spatial Variabilty of Nutrients, electrival Conductivity and Yield and Site-Specific Fertilizers management in a Paddy Field.* The Ph. D (Doctoral dissertation,Thesis, Faculty of Engineering, Universiti Putra Malaysia).

Fee, C.G. (2011). Management of Ganoderma Diseases in Oil Palm Plantations. *The Planter*, *87*(39), 325–339.

Flood, J., Hasan, Y., Turner, P.D., and Grady, E.B.O. (2000). The Spread of Ganoderma from Infective Sources in the Field and its Implications for. *CAB International*, 101–112.

Garrett, S., and Leader, S. P. (1997). Tree defect detection.*agris.fao.org*

Hasan, Y.P. (1998). The comparative of different oil plam tissues as infection sourced for basal stem rot in replantings. *Planter*, 74(864), 119-135.

Idris, A., Ismail, S., and Ariffin, D. (2004). Innovative technique of sanitation for controlling Ganoderma at replanting. *MPOB Information Series*, 3–6.

Idris, A., Ismail, S., Ariffin, D., and Ahmad, H. (2002). *MPOB Information Series*, *131*, 1–2.

Idris, A. S., Mazliham, M. S., Loonis, P., and Wahid, M.B. (2010). GanoSken For early detection of Ganoderma Infection in oil palm. *MPOB Information Series*, 3–6.

Idris, A. S., Yamaoka, M., Hayakawa, S., Basri, M. W., Noorhashimah, I., and Ariffin, D. (2003). PCR technique for detection of Ganoderma. *MPOB Information Series*, (June), 1–4.

Idris, A.S., Ismail , S.,and Ariffin, D. (2004a). Innovative Tecnique of Sanitation for Controlling Ganoderma at Replanting. *MPOB Information Series No.213.4 pp*.

Idris, A.S., Kushairi, A., Ariffin, D., and Basri, W. (2006). Techniques for Inoculation of Oil Palm Geminated Seeds with Ganoderma. *MPOB Information Series, No.314*, 4.

Izzuddin, M., Idris, A. ., Wahid, O., Nishfariza, M. ., & Shafri, H. Z. . (2012). Field spectroscopy for detection of Ganoderma Disease in Oil Palm. *MPOB Information Series*, *532*, 1–4.

Kandan, A., Bhaskaran, R., and Samiyappan, R. (2010). Ganoderma – a basal stem rot disease of coconut palm in south Asia and Asia pacific regions. *Archives Of Phytopathology And Plant Protection*, *43*(15), pp 1445–1449. http://doi:10.1080/03235400802536527.

Khairuddin, H. (2008). An overview of the current status of Ganoderma basal stem rot and its management in a large plantation group in Malaysia. *The Planter*, 84:469-482.

Khairudin, H. (1995). Basal stem rot of oil palm caused by Ganoderma boninense: A update. *In Proceedings 1993 PORIM International Palm Oil Congress-Agriculture. Palm Oil Research Institute, Kuala Lumpur, Malaysia.pg*, (pp. 739-749).

Larsson, B., Bengtsson, B., and Gustafsson, M. (2004). Nondestructive detection of decay in living trees, Tree Physiology,24(1),pp 853–858 doi:10.1093/treephys/24.7.853

Liaghat, S., Mansor, S., Ehsani, R., Shafri, H. Z. M., Meon, S., & Sankaran, S. (2014). Mid-infrared spectroscopy for early detection of basal stem rot disease in oil palm. *Computers and Electronics in Agriculture*, *101*, 48–54. doi:10.1016/j.compag.2013.12.012.

Lim, K., and Udin, W. (2010). Management of Ganoderma in peat soil in Indonesia. . *In Proceedings of the Second International Seminar on Oil Palm Diseases: Advances in Ganoderma Research and Management, Ed. by Purba, AR.*

Lin, C.S., Chung, C.H., Yang, T.H., and Lin, F.C., (2012). Detection of Electric Resistivity Tomography and Evaluation of the Sapwood-Heartwood Demarcation in Three Asia Gymnosperm Species, *Silva Fennica,46(3)*, 415–424.

Mattheck, C.G., and Bethge, K.A. (1993). Detection of decay in trees with metriguard stress wave timer. *Journal of Arboriculture*,19,pp 374.

Mazliham, M.S., Loonis, P., and Idris, A. (2008). Interpretation of Sound Tomography Image for the Recognition of Ganoderma Infection Level in Oil Palm, *In Trends in Intelligent Systems and Computer Engineering,Springer US* pp 409–426.

Meor, Y., Khalid, M. A., and Seman, I. A. (2009). Identification of Basal Stem Rot disease in local. *Journal of Nuclear and Related Technologies*, *6*(1), 282–287.

Mohammed, C., Rimbawanto, A., and Page, D.E. (2014). Management of basidiomycete root- and stem-rot diseases in oil palm, rubber and tropical hardwood plantation crops. *Forest Pathology*, *44*(6), 428–446. doi:10.1111/efp.12140

Moore.W., (1999). The combined use of the resistograph and the shigometer for the accurate mapping and diagnosis of the internal condition of woody support organs. *The International Journal of Urban Forestry*, *23:3*(February 2014), 273–287.

Najmie, M., Khalid, K., Sidek, A., and Jusoh, M. (2011). Density and Ultrasonic Characterization of Oil Palm Trunk. *Measurement Science Review*, *11*(5), 160–164.

Nelson, M., Felix-Gastelum, R., Orum, T., Stowell, L., and Myers, D. (1994). Geographic information systems and geostatistics in the design and validation of regional plant virus management programs. *Phytopatology, 84(9)*, 898-905.

Ommelna, B., Jennifer, A., and Chong, K. (2012). The potential of chitosan insuppresing Ganoderma boninense infection in oil plam seedling. *J. Sustain Sci Manage 7(2)*, 186-192.

Pakiam, R., (2013). Palm Oil Advances as Malaysia's export tac may boost shipments. *Blomberg,Jan*.

Paysen, T.E., Narog, M.G., and Zavala, M.A. (1992). Monitoring Electrical Resistance in Canyon Live Oak,Using a Shigometer.In Symposium on Ecology and Management of Oak and Associated Woodlands: Perspectivesin Southwestern United States and New Mexico, pp 199–203.

Rankine, I., and Fairhurst, T. (1999). Management of phosphorus, potassium and magnesium in mature oil palm. *Better Crops International*, *13*(1), 10–15. p10.pdf.

Rees, R. W., Flood, J., Hasan, Y., Potter, U., and Cooper, R. M. (2009). Basal stem rot of oil palm (Elaeis guineensis); mode of root infection and lower stem invasion by Ganoderma boninense. *Plant Pathology*, *58*(5), 982–989. doi:10.1111/j.1365-3059.2009.02100.x.

Sariah, M., Zakaria, H., Flood, J., Bridge, P., & Holderness, M. (2000). The use of soil amendments for the control of basal stem rot of oil-palm seedlings. In *Ganoderma diseases of perennial crops* (pp. 88-89).

Sharples, A. (1936). Disease and pests of the rubber tree. In *Disease and pests of the rubber tree.Macmillan & Co.Ltd, London.*pp 477

Shigo A.L and Shigo A. (1974). Detection of Discoloration and Decay in Living Trees and Utility Poles. *USDA Forest Services research Paper*, 11.

Shortle, W. (2001). Shigometer. *Encyclopedia of Plant Pathology*, *2*, 902–903. doi:ISBN 0-471-29817-4.

Singh, G.D. (1991). Ganoderma- the scourage og oil palm in the coastal area. *In Proccedings of Ganoderma workshop* (pp. 7-35). Bangi, Sleangor, Malaysia: Palm Oil Research Institute of Malaysia.

Smith, K., and Shortle, W. (1988). Electrical resistance and wood decay by white rot fungi. *Mycologia*, 124-126.

Subagio, A., and Foster, H. (2003). Implication of Ganoderma disease on loss in stand and yield production of oil palm in North Sumatra. *In Proceedings of the MAPPS Conference.*

Sudduth, K., Fraisse, C., Drummond, S., and Kitchen, N. (1998). Integrating spatial data collection, modelling and analysis for precision agriculture. *In First International Conference on Geospatial Information in Agriculture and Forestry.* Lake Buena Vista, Florida.

Sulaiman, O., Salim, N., Nordin, N. A., Hashim, R., Ibrahim, M., and Sato, M. (2012). The potential of oil palm trunk biomass as an alternative source for compressed wood. *Bioresources.com*, *7*, 2688–2706.

Susanto, A., Sudharto, P. S., and Purba, R. Y. (2005). Enhancing biological control of basal stem rot disease (Ganoderma boninense) in oil palm plantations. *Mycopathologia*, *159*(1), 153–7. doi:10.1007/s11046-004-4438-0.

Tattar, T. S. (1972). Relationship between the degree of resistance to a pulsed electric current and wood in progressive stages of discoloration and decay in living trees. *Canadian Journal of Forest Research*, 2(3),236-243.

Tattar, T.S. and Blanchard, R. (1976). Electrophysiological research in plant pathology. *Annual Review of Phytopathology*, (98), 309–325. Retrieved from http://www.annualreviews.org/doi/pdf/10.1146/annurev.py.14.090176.001521.

Thompson, A. (1931). Stem-rot of the oil palm in Malaya.Bull*. Department Agric.,Stariats Settlements and FMS.Sci. Series 6.*

Tsoumis, G. (1991). Science and technology of wood. Structure,properties, utlization. *Van Nostrand Reinhold, New York.*

Turner, P. D. (1981). Oil palm diseases and disorders. *Oxford University press, Oxford*,pp 280

Utomo, C., and Niepold, F. (2000). Development of Diagnostic Methods for Detecting Ganoderma-infected Oil Palms. *Journal of Phytopathology, 148*(9-10), 507–514.

Wardlaw, C.W. (1946). A wilt disease of the oil palm. *Nature 158*, 56.

Wong, L., Bong, C.F., and Idris, A. . S. (2012). Ganoderma Species Associated with Basal Stem Rot Disease of Oil Palm. *American Journal of Applied Sciences*, *9*(6), 879–885.

Yamaguchi, T., Sasaki, K., and Sakamoto, Y. (2001). Evaluation of a Stress-wave Timer for the Minimally Destructive Detection of Decay in Living Trees in Northern-Japanese Forests. *Journal of Forest Research*, *6*(2), 117–120.