

**MODELLING THE YIELD LOSS OF OIL PALM  
DUE TO *Ganoderma* BASAL STEM ROT  
DISEASE**

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PERPUSTAKAAN  
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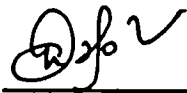
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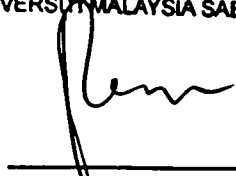
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## ABSTRACT

Oil palm or scientifically known as *Elaeis guineensis* Jacq. is the most efficient oilseed crop in the world. This commodity crop is considered as the golden crop in Malaysia. This is due to the contribution of the oil palm industry to the country's overall economy, providing both employment and income from exports. The efforts of the country to strengthen the industry are being interrupted by a fatal disease which is called as *Ganoderma* Basal Stem Rot (BSR) disease. This disease can cause a significant economic loss to the industry. To date, there is still no effective control of the disease at the commercial fields' level. The existing control measures can only prolong the productive life of the infected palms. It is very crucial to the planters to estimate the yield loss due to the disease. Currently, there is no existing mathematical model that can be used for that purpose. Therefore, this empirical study was conducted to build a mathematical model which can be used for yield loss estimation due to the disease. For the purpose of data collection, three commercial oil palm plots with different production phase (i.e. step ascent phase, plateau phase, and declining phase) were selected as the study sites. The yield and disease severity of the selected palms in the three study sites were recorded for the duration of twelve months. Before building the yield loss model, a data screening was performed in order to remove palms with extreme yield values. The identification of the main sources of multicollinearity was also performed based on correlation-based test and also variance-based test. All the remaining data set was splitted into model building data set and validation data set. Two model building approaches were applied, which are estimation-post-selection and Bayesian model averaging (BMA). For estimation-post-selection approach, there were two subset selection algorithms were applied, namely backward stepwise subset selection and best-subset selection. The best single model from the best-subset selection algorithm was chosen based on eight criteria, namely Akaike Information Criterion (AIC), Finite Prediction Error (FPE), Generalised Cross Validation (GCV), Hannan-Quinn (HQ), RICE, SCHWARZ, sigma square (SGMASQ) and SHIBATA. The predictive performance of the three best models which represent three different model building algorithms were assessed and compared. Based on mean square error (MSE), root mean square error (RMSE), and mean absolute error (MAE), BMA model has the lowest values, thus selected as the best model for oil palm yield loss. This best model (i.e. estimated loss of total bunch weight in 12 months =  $-24.632 + (-18.307*R2) + (13.456*R3) + (21.531*R4) + (2.346*AUDPC) + (0.551*NEIGHBOUR) + (35.113*PT) + (0.014*AUDPC*NEIGHBOUR) + (-0.011*AUDPC*PT)$ ) revealed that planting technique as the most important predictors of oil palm yield loss and followed by disease progress (AUDPC), disease severity (mild, medium, and severe), number of infected neighbouring palms, and two interaction variables. The economic loss was then estimated by using the best model. The estimated economic loss showed that the loss can be up to 68 percent as compared to the attainable yields of all the infected palms. In conclusion, the yield loss model built in this study can potentially be used by the oil palm planters in helping them to estimate the yield loss as well as economic loss due to *Ganoderma* BSR disease if no treatment is applied.

## ABSTRAK

### **PEMODELAN KERUGIAN HASIL KELAPA SAWIT DISEBABKAN OLEH PENYAKIT Ganoderma REPUT PANGKAL BATANG**

*Kelapa sawit atau nama saintifiknya *Elaeis guineensis* Jacq. merupakan tanaman benih minyak yang paling cekap di dunia. Tanaman komoditi ini dianggap sebagai tanaman emas di Malaysia. Gelaran ini diberi kerana sumbangan industri minyak sawit kepada ekonomi negara secara keseluruhan dengan menyediakan peluang pekerjaan dan pendapatan melalui eksport. Namun, usaha negara ini untuk mengukuhkan industri ini sedang diganggu oleh satu penyakit yang dikenali sebagai Ganoderma Reput Pangkal Batang (RPB). Penyakit ini boleh menyebabkan kerugian ekonomi yang signifikan kepada industri. Setakat ini, masih tiada kawalan yang berkesan bagi penyakit ini di peringkat ladang komersial. Kaedah-kaedah kawalan sedia ada hanya boleh memanjangkan jangka hayat produktif pokok yang dijangkiti. Penganggaran kerugian hasil yang disebabkan oleh penyakit ini adalah sangat penting kepada pengusaha sawit. Namun, pada masa ini tiada model matematik sedia ada yang boleh digunakan untuk tujuan tersebut. Oleh itu, kajian empirikal ini telah dijalankan untuk membina model matematik yang boleh digunakan untuk menganggar kerugian hasil disebabkan oleh penyakit ini. Bagi tujuan pengumpulan data, tiga plot komersial kelapa sawit dengan fasa pengeluaran yang berbeza (iaitu fasa menaik, fasa mendatar dan fasa menurun) telah dipilih sebagai plot kajian. Hasil dan tahap penyakit bagi setiap pokok kelapa sawit yang dipilih dalam tiga plot kajian dicatatkan bagi tempoh dua belas bulan. Sebelum membina model kerugian hasil, pemeriksaan data telah dilakukan dalam usaha untuk menyingkirkan pokok kelapa sawit yang menunjukkan data hasil yang ekstrem. Pengenalpastian sumber utama multikolinearan juga dilakukan berdasarkan ujian berdasarkan korelasi dan ujian berdasarkan varians. Semua set data yang tinggal telah dipecahkan kepada set data untuk pembangunan model dan set data untuk pengesahan. Dua pendekatan pembangunan model telah digunakan iaitu pemilihan selepas anggaran dan pemurataan model Bayesian (BMA). Bagi pendekatan pemilihan selepas anggaran, terdapat dua algoritma pemilihan subset telah digunakan, pemilihan subset langkah demi langkah iaitu ke belakang dan pemilihan terbaik subset. Model tunggal terbaik daripada algoritma pemilihan terbaik subset dipilih berdasarkan lapan kriteria iaitu Kriteria Maklumat Akaike (AIC), Ralat Ramalan Terhingga (FPE), Pengesahan Silang Am (GCV), Hannan–Quinn (HQ), RICE, SCHWARZ, sigma kuasa dua (SGMASQ) dan SHIBATA. Prestasi ramalan tiga model terbaik yang mewakili tiga algoritma pembinaan model yang berbeza telah dinilai dan dibandingkan. Berdasarkan ralat min kuasa dua (MSE), punca min ralat kuasa dua (RMSE) dan min ralat mutlak (MAE), model BMA mempunyai nilai yang terendah, sekali gus dipilih sebagai model yang terbaik untuk kerugian hasil kelapa sawit. Model terbaik ini (iaitu anggaran kerugian jumlah berat tandan dalam 12 bulan =  $-24.632 + (-18.307 \cdot R2) + (13.456 \cdot R3) + (21.531 \cdot R4) + (2.346 \cdot \text{AUDPC}) + (0.551 \cdot \text{NEIGHBOUR}) + (35.113 \cdot \text{PT}) + (0.014 \cdot \text{AUDPC} \cdot \text{NEIGHBOUR}) + (-0.011 \cdot \text{AUDPC} \cdot \text{PT})$ ) telah mendedahkan bahawa teknik penanaman sebagai faktor yang paling penting dalam penganggaran kerugian hasil kelapa sawit dan diikuti oleh progres penyakit (AUDPC), tahap penyakit (ringan, sederhana dan teruk), bilangan pokok jiran dijangkiti dan dua*

*pembolehubah interaksi. Kemudian, kerugian ekonomi telah dianggarkan dengan menggunakan model terbaik tersebut. Kerugian ekonomi yang dianggar menunjukkan bahawa kerugian boleh mencecah sehingga 68 peratus berbanding dengan kadar hasil yang boleh dicapai bagi semua pokok yang dijangkiti. Kesimpulannya, model kerugian hasil yang dibina dalam kajian ini berpotensi untuk digunakan oleh penanam kelapa sawit dalam membantu mereka untuk menganggarkan kerugian hasil serta kerugian ekonomi akibat penyakit Ganoderma BSR jika tiada rawatan digunakan.*



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## LIST OF ABBREVIATIONS

<b>8SC</b>	-	Eight selection criteria
<b>AIC</b>	-	Akaike information criterion
<b>AUDPC</b>	-	Area under the disease progress curve
<b>BIC</b>	-	Bayesian information criterion
<b>BMA</b>	-	Bayesian model averaging
<b>BSR</b>	-	Basal stem rot
<b>CSR</b>	-	Complete spatial randomness
<b>df</b>	-	Degree of freedom
<b>ESS</b>	-	Error sum of squares
<b>FAO</b>	-	Food and Agriculture Organization
<b>FELCRA</b>	-	Federal Land Consolidation and Rehabilitation Authority
<b>FELDA</b>	-	Federal Land Development Authority
<b>FFB</b>	-	Fresh fruit bunch
<b>FPE</b>	-	Finite Prediction Error
<b>GCV</b>	-	Generalised Cross Validation
<b>GIS</b>	-	Geographical information system
<b>GMP</b>	-	Good management practice
<b>GSM</b>	-	<i>Ganoderma</i> selective medium
<b>HQ</b>	-	Hannan–Quinn
<b>MAE</b>	-	Mean absolute error
<b>MCMC</b>	-	Markov chain Monte Carlo
<b>MPOB</b>	-	Malaysian Palm Oil Board
<b>MS</b>	-	Mean square

<b>MSE</b>	-	Mean square error
<b>NNA</b>	-	Nearest neighbour analysis
<b>OER</b>	-	Oil extraction rate
<b>OLS</b>	-	Ordinary least squares
<b>PCR-DNA</b>	-	Polymerase Chain Reaction- Deoxyribonucleic acid
<b>PIP</b>	-	Posterior inclusion probability
<b>PMP</b>	-	Posterior model probability
<b>PPMC</b>	-	Pearson product moment correlation coefficient
<b>RISDA</b>	-	Rubber Industry Smallholders Development Authority
<b>RSPO</b>	-	Roundtable on Sustainable Palm Oil
<b>RSS</b>	-	Regression sum of squares
<b>SGMASQ</b>	-	Sigma square
<b>SRS</b>	-	Simple random sampling
<b>SS</b>	-	Sum of square
<b>TBW</b>	-	Total bunch weight
<b>TSS</b>	-	Total sum of squares

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# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

Oil palm or scientifically known as *Elaeis guineensis* Jacq. is a monocotyledonous tree which belongs to the *Palmae* family and the *Cocoidae* subfamily. This perennial tree crop (i.e. the tree which can live more than two years) is being used extensively in food and non-food industries. It can grow over 100 years or more to a height of up to 15 meters. Its productive commercial life is only around 20 to 30 years. Oil palm produces two types of oil, which are palm oil (i.e. the primary product) and palm kernel oil (Sime Darby Plantation, 2013). This commodity crop is the most efficient oilseed crop in the world or the highest yields per hectare of all crops (Murphy, 2014).

One hectare of oil palm plantation is able to produce up to ten times more oil (i.e. 4.14 tonnes per hectare per year) than other leading oilseed crops, such as soybean (i.e. 0.4 tonnes per hectare per year), sunflower (i.e. 0.55 tonnes per hectare per year), and rapeseed (i.e. 0.72 tonnes per hectare per year) (Corley and Tinker, 2016). Furthermore, oil palm only accounted for 5.3% of global land use for cultivation of ten major oilseeds in the world with the total of 253.9 million hectares. It is lower than soybean (40.9%), cottonseed (13.2%), rapeseed (13.0%), and sunflower (9.4%).

This crop has produced around 33% of global oils and fats output in 2014 which is the highest as compared to other oilseeds (i.e. 23% by soybean, 13% by rapeseed, 13% by animal fats, 8% by sunflower, 2% by coconut oil, and 8% by others) (Malaysian Palm Oil Council, 2015). Palm oil was also the highest consumed oil in the world in 2011 as compared to the 17 oils and fats with 47.05% of the world consumption of oils and fats (Sime Darby Plantation, 2013).

## **1.2 Contribution of Oil Palm Industry to the Malaysian Economy**

There is a quote saying that oil palm is a 'nature's gift to Malaysia and Malaysia's gift to the world' (Mohd Basri, Chan, and Rubaah, 2009). Oil palm is the most important commodity crop in Malaysia, thus recognized as the golden crop of this country. The palm oil industry has been significantly contributing to Malaysia's overall economy, providing both employment and income from exports. In 2011, this industry has contributed 9% to the Malaysian gross domestic products. Furthermore, it has also created 451,507 paid jobs in 2014 (Department of Statistics Malaysia, 2015), which is 27% of the total employment in the agriculture sector in Malaysia (Malaysia Productivity Corporation, 2015). In term of contribution to the national income, the industry through its various oil palm products has contributed around RM80.4 billion to the total export revenue in 2011, which is around 12% of the total export revenue (i.e. RM694.5 billion) of the country during that year (Malaysian Palm Oil Board, 2015a).

Oil palm was commercially planted in Malaysia in 1911 at Tenammaran Estate, Kuala Selangor (Teoh, 2002; Yusof and Chan, 2004). The oil palm industry has been playing a very significant role in strengthening the agriculture sector in this country. Currently, oil palm is utilizing more than 5.3 million hectares of land or 71% of the agriculture land, which is equivalent to 14.3% of the total land area in Malaysia (Malaysian Palm Oil Board, 2015a). A total of 4.3 thousand hectares (86%) and 697.8 hectares (14%) of the oil palm area are currently cultivated by estates and smallholdings respectively. In Malaysia, the producers of oil palm are divided into six categories, which are private estates, government schemes (e.g.

FELDA, FELCRA, and RISDA), government or estate agencies, and independent smallholders with the share of oil palm planted area in 2012 was 61.6%, 18.7% (13.9% of FELDA, 3.3% of FELCRA, and 1.5% of RISDA), 6.0%, and 13.6% respectively (Malaysian Palm Oil Board, 2013a).

The state of Sabah is still leading the oil palm industry as compared to other states in terms of production and also oil palm planted area. The current figure shows that the total oil palm planted area in the state is around 1.51 million hectares or 28% of the total oil palm planted area in Malaysia (Malaysian Palm Oil Board, 2015a). In Sabah, oil palm currently takes up almost 90% of the total state agriculture land, and is mostly concentrated in the palm oil belt stretching from the district of Sandakan to Lahad Datu.

In the world scenario, Malaysia is the second largest palm oil producer and exporter after Indonesia. In 2014, Malaysia's palm oil alone has contributed 39% or 17.31 million tonnes of the total global trade of oils and fats (Malaysian Palm Oil Council, 2015). Due to the increasing positive trend in the world demand of edible oil especially the palm oil, the country has taken many efforts to response to the world demand by increasing the production as well as the productivity of its oil palm. These efforts can be seen through the oil palm planted area which is now more than five million hectares and also through the extensive effort in research and development on oil palm.

In 2014, Malaysia has exported 64.8% or 11.2 million tonnes of its palm oil and kernel oil to only these six countries, which are India (3.2 million tonnes), China (2.8 million tonnes), EU-28, Pakistan, USA, Vietnam, and Japan (Malaysian Palm Oil Council, 2015). This shows that India is currently the main importer of Malaysian palm oil. China used to be the main importer of Malaysia but this country has recently increased its import on soybean oil. Pakistan has also reduced the import due to the increased in its import on soybean oil and rapeseed oil. For palm kernel oil, the two major destinations of export are USA and China with the total of 0.29 million tonnes (or 24.6% of the total palm kernel oil exports) and 0.18 million tonnes (or 15.3%) respectively in 2011 (Malaysian Palm Oil Board, 2013b).

The oil palm industry is directed to achieve the vision of 35:25, which is 35 tonnes of fresh fruit bunch (FFB) per hectare per year with 25 oil extraction rate (OER) (Yusof and Mohd Arif, 2005). The current achievement is 19.67 tonnes and 20.62% of FFB per hectare per year and OER respectively (Malaysian Palm Oil Board, 2015a). Unfortunately, the efforts of the country to focus on the improvement of the production as well as the productivity of this oil palm industry are being interrupted by the attack of a fatal crop disease. As far as the disease problem to oil palm in Malaysia is concerned, *Ganoderma* disease which includes basal stem rot (BSR) and upper stem rot (USR) remains as the most devastating disease. It is present in more than 50% of the oil palm fields in Malaysia (Idris, Mior, Maizatul, and Ahmad Kushairi, 2011). Furthermore, this disease is also considered as the most destructive disease of oil palm in South-East Asia (Ariffin, Idris, and Singh, 2000).

### **1.3 Incidence of *Ganoderma* Basal Stem Rot (BSR) Disease and Its Economic Impact**

*Ganoderma* Basal Stem Rot (BSR) disease is the most widely studied and knowledge available oil palm disease in Malaysia (Idris, 2012). The disease is caused by the white rot fungus *Ganoderma* (Flood, Hasan, Turner, and O'Grady, 2000). In the region of Southeast Asia especially in Malaysia and Indonesia, this disease is considered as the most devastating disease. In the region of Africa, vascular or *Fusarium* wilt is the most serious field disease of oil palm (Ariffin and Mohd Basri, 1993). In some countries in Africa (i.e. Angola, Cameroon, Ghana, Nigeria, Zambia, San Tome, Principe, Tanzania, Zimbabwe, and Republic of Congo), in Central America (i.e. Honduras), and in Oceania (i.e. Papua New Guinea), some oil palm fields were reported to be infected by *Ganoderma* BSR disease (Ariffin *et al.*, 2000). There are many species of *Ganoderma* reportedly have caused the disease, but *Ganoderma boninense* was identified as the main species that causes the disease (Ho and Nawawi, 1985; Siang *et al.*, 2013; Wong, Bong, and Idris, 2012). The disease was previously considered as an economically unimportant disease due to the fact that the disease only attacks older palms which are soon be



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