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Economic Loss due to Ganoderma Disease in Oil Palm

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Abstract**—**Oil palm or *Elaeis guineensis* is considered as the golden crop in Malaysia. But oil palm industry in this country is now facing with the most devastating disease called as Ganoderma Basal Stem Rot disease. The objective of this paper is to analyze the economic loss due to this disease. There were three commercial oil palm sites selected for collecting the required data for economic analysis. Yield parameter used to measure the loss was the total weight of fresh fruit bunch in six months. The predictors include disease severity, change in disease severity, number of infected neighbor palms, age of palm, planting generation, topography, and first order interaction variables. The estimation model of yield loss was identified by using backward elimination based regression method. Diagnostic checking was conducted on the residual of the best yield loss model. The value of mean absolute percentage error (MAPE) was used to measure the forecast performance of the model. The best yield loss model was then used to estimate the economic loss by using the current monthly price of fresh fruit bunch at mill gate.

Keywords**—***Ganoderma*, oil palm, regression model, yield loss, economic loss.

I. Introduction

MALAYSIA is the second main producer of palm oil in the world after Indonesia. But the planters of oil palm in this country are facing with a serious crop disease infection which is called as Ganoderma Basal Stem Rot (BSR) disease or popularly known as Ganoderma disease [1]. The disease is caused by a fungal which is called as Ganoderma. *Ganoderma boninense* species was claimed as the main species causes the disease [2]. It was estimated that the total area affected by Ganoderma disease in 2020 would be around 443,430 ha or 65.6 million of palm trees [3]. This disease is the most widely studied and knowledge available of oil palm disease in Malaysia. The disease can reduce the yield of the infected palms either from total yield loss by killing the infected palms (or also called as direct loss) or reduced yield by reducing the weight or the number of fresh fruit bunch (FFB) in infected palms but still living palms (or indirect loss).

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There are many control measures or methods have been used or developed in order to minimize the economic loss due to the disease, such as removing or destroying the infected palms, applying some treatments to the infected palms (also called as a curative control), or protecting the healthy or young palms from being infected (also called as a preventive control) [4]. Currently, there is still no effective cure for Ganoderma disease in an existing stand [5]. Most of the control measures can only prolong the productive lifespan of the infected palms without totally curing the disease. Hence, estimation of loss due to the disease is very crucial to the planters in order to identify the control measures that can help them in minimizing the loss. Currently, there is still no specific mathematical model available to estimate the yield loss due to Ganoderma disease. Previously, most of the estimated yield losses were calculated based on the total loss or number of dead palms due to the disease without taking into account the yield loss by the infected but still standing palms [3]. Therefore, the objective of this study is to develop a yield loss model of oil palm due to Ganoderma disease and then use the model to estimate the economic loss.

II. Materials and Methods

A. Study Plots

There were three commercial oil palm sites selected for collecting the data required in developing the yield loss model. The sampling unit of the study is an individual palm. All the infected palms by Ganoderma disease in the study sites were selected and monitored. Some uninfected palms or healthy palms were also randomly selected and monitored as control. The location (altitude) of the study sites are Latitude 4°25'53.76"N, Longitude 117°45'8.64"E for study site 1 (the plot ID is MBE07), Latitude 4°19'24.96"N, Longitude 118°05'26.88"E for study site 2 (the plot ID is SKE02), and Latitude 4°46'19.35"N, Longitude 118°8'18.67"E for study site 3 (the plot ID is MDE87). All of the study sites are managed by the same oil palm company and are located in Tawau district of Sabah, Malaysia.

B. Yield Loss Calculation

Yield loss or damage is a standard term represents the difference between the attainable and the actual yield [6]; that is, the yield loss from diseases' injuries. Attainable yield corresponds to the yield that would be produced by a crop when free of injuries. Yield loss, YL_i is frequently expressed as the fraction of the attainable yield loss to disease injuries and it is computed as in (1) [7], [8]:

$$YL_i = \overline{Y} - Y_i \quad (1)$$

where $\overline{Y}$ denotes the average yield of the uninjured palms which are not infected by *Ganoderma* disease and Y_i denotes the yield of i-th palm.

C. Developing Yield Loss Model

Backward elimination based regression method was used in developing the yield loss model where the independent variables also include first order interaction variables. Combination of multicollinearity analysis and backward elimination regression analysis was used to select the best set of independent variables for estimating yield loss of oil palm due to Ganoderma disease. The initial general regression model can be written as in (2) [9]:

$$Y = \Omega_0 + \Omega_1 W_1 + \Omega_2 W_2 + ... + \Omega_k W_k + \mu \quad (2)$$

where Y denotes the dependent variable, W_k denotes the j-th independent variable (can be single quantitative, interaction, transformed, generated or dummy) for $j = 1, 2, ..., k$. The Ω_k denotes j-th coefficient of independent variable for W_k where $j = 1, 2, ..., k$, while Ω_0 denotes the constant term of the model, and μ denotes the random error of the model.

After identifying and estimating the best model, the model's goodness-of-fit was checked by conducting residual analysis on the standardized residuals. The residual analysis includes random errors or normality checking, homoscedasticity checking by producing a scatterplot of the standardized residuals against the fitted values, independent residuals or autocorrelation checking by using Durbin-Watson test, and outliers checking by identifying the absolute value of standardized residual which is larger than 3. After that, the model accuracy or out-of-sample forecast performance was measured by using mean absolute percentage error (MAPE). MAPE or also known as mean absolute percentage deviation (MAPD) is calculated by using (3):

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{A_i - F_i}{A_i}\right| \times 100 \quad (3)$$

where A_i denotes the actual value of the i-th observation and F_i denotes the estimated value of the i-th observation based on the best model developed. A value of MAPE less than 10% indicates highly accurate forecasting, 10% to 20% indicates good forecasting, 20% to 50% is reasonable forecasting, and 50% or more indicates inaccurate forecasting [10]. Statistical Package for Social Science (SPSS) version 21 was used for data analysis.

III. Results and Discussion

A. Distribution of the Infected Oil Palms Based on the First Disease Census

Table I shows the distribution of infected palms according to disease severity and study site.

TABLE I
DISTRIBUTION OF INFECTED PALMS ACCORDING TO DISEASE SEVERITY AND STUDY SITE

Disease severity	No. of palms			TOTAL
	MBE07	SKE02	MDE87	
R1 – Healthy	65	65	65	195
R2 – Mild	8	29	24	61
R3 – Medium	11	18	57	86
R4 – Severe	9	11	49	69
TOTAL	**93**	**123**	**195**	**411**

B. Average Yield of Uninfected Palms

Table II shows the descriptive statistics of a total of 167 uninfected palms or palms rated as R1 (originally 195 palms but 28 were excluded due to missing cases) from all the study sites. On average, an uninfected palm planted in the study sites could produce 80.92 kilogram of FFB or total bunch weight (TBW) in six months with the standard deviation of 34.45 kilogram. This average yield is also within the range of the potential yield estimated by past study [11]. Kolmogorov-Smirnov test for normality has confirmed that the distribution of the TBW data from these 167 uninfected palms is normal [statistic value = 0.058 (df = 166), p = .200].

TABLE II
DESCRIPTIVE STATISTICS OF TBW DATA FOR THE UNINFECTED PALMS (N=167)

		Statistic
Mean		80.92
95% Confidence Interval for Mean	Lower Bound	75.64
	Upper Bound	86.20
5% Trimmed Mean		80.12
Median		77.00
Variance		1187.06
Std. Deviation		34.45
Minimum		19.00
Maximum		162.00
Range		143.00
Interquartile Range		48.25
Skewness		0.319
Kurtosis		-0.577

By using the value of 80.92 ≈ 80 kilogram as the average yield or attainable yield of uninfected palms, the yield loss data was generated using (1).

C. Modeling the Yield Loss

Table III shows the dependent variable and independent variables where the independent variables include categorical and continuous variables. Before estimating the yield loss model, all the categorical variables were transformed into dummy variables as shown in Table IV.

TABLE III
VARIABLES

Variable	Role	Type
Yield loss	Dependent	Continuous
Disease severity	Independent	Categorical
Change in disease severity	Independent	Continuous
No. of infected neighbor palms	Independent	Continuous
Age of oil palm	Independent	Continuous
Topography	Independent	Categorical
Generation	Independent	Categorical

TABLE IV
CATEGORICAL VARIABLES CODINGS

Variable	Category	Label used in equation	Parameter coding			
Disease severity	R1 - Healthy		0	0	0	0
	R2 – Mild	R2	0	1	0	0
	R3 - Medium	R3	0	0	1	0
	R4 - Severe	R4	0	0	0	1
Topography	Flat		0			
	Undulating	TOPOGRAPHY	1			
Generation	1st generation		0			
	2nd generation	GENERATION	1			

A variance based test which is variance inflation factor (VIF) was used to check the multicollinearity problem. All the independent variables with the VIF value of 5 and above were removed one by one starting with the highest value of VIF [12].

By using backward elimination approach, there are 16 models (Model 1 until Model 16) were estimated. Table V shows the summary of all these models.

TABLE V
MODEL SUMMARY

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.644	0.414	0.369	28.370
2	0.644	0.414	0.371	28.325
3	0.644	0.414	0.373	28.279
4	0.644	0.414	0.375	28.236
5	0.643	0.414	0.377	28.194
6	0.643	0.414	0.378	28.155
7	0.643	0.414	0.38	28.112
8	0.643	0.413	0.382	28.078
9	0.642	0.413	0.383	28.046
10	0.642	0.412	0.384	28.019
11	0.641	0.411	0.385	28.008
12	0.639	0.408	0.384	28.028
13	0.637	0.406	0.384	28.027
14	0.634	0.402	0.381	28.083
15	0.631	0.398	0.379	28.128
16	0.626	0.392	0.375	28.220

The best model is Model 16 since all the independent variables significantly affect the yield loss [$F(9,324) = 23.242$, $p < .05$, $R^2 = 0.392$]. There were ten independent variables ($p < .05$) including constant left in Model 16 as shown in Table VI. Eight of the independent variables are first order of interaction variables.

TABLE VI
COEFFICIENTS

Variables	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-11.422	5.892		-1.938	0.053
AGE	0.923	0.299	0.197	3.092	0.002
R3_NEIGHBOR	5.104	2.505	0.124	2.038	0.042
R3_AGE	0.900	0.259	0.236	3.475	0.001
R4_AGE	1.520	0.235	0.328	6.464	0.000
R2_GENERATION	41.643	11.098	0.362	3.752	0.000
R3_GENERATION	23.345	6.951	0.159	3.358	0.001
R4_GENERATION	28.626	10.046	0.130	2.850	0.005
R2_TOPOGRAPHY	-34.659	11.995	-0.274	-2.890	0.004
NEIGHBOR_GENERATION	-4.853	2.382	-0.107	-2.037	0.042

Table VII shows the statistics of the residuals with the mean and standard deviation value of the standardized residuals are 0 and close to 1 (0.986 ≈1) respectively. Fig. 1 shows the distribution of the standardized residual which also indicates that the distribution is almost similar with the normal distribution line. Fig. 2 shows that there is no clear systematic pattern which indicates homoscedasticity of the residuals. All the standardized residuals also lie between ±3 which indicates there is no outlier in the residuals. The value of Durbin-Watson is close to 2 (i.e. 1.559 ≈ 2) and it has confirmed that the residuals are independent and no issue of autocorrelation [12]. All the goodness-of-fit measures showed that the best model identified in this study has a good fit to predict or estimate the yield loss of infected palms.

TABLE VII
RESIDUAL STATISTICS

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-18.592	61.509	15.8443	22.366	334
Residual	-79.589	72.739	0	27.836	334
Std. Predicted Value	-1.540	2.042	0	1	334
Std. Residual	-2.820	2.578	0	0.986	334

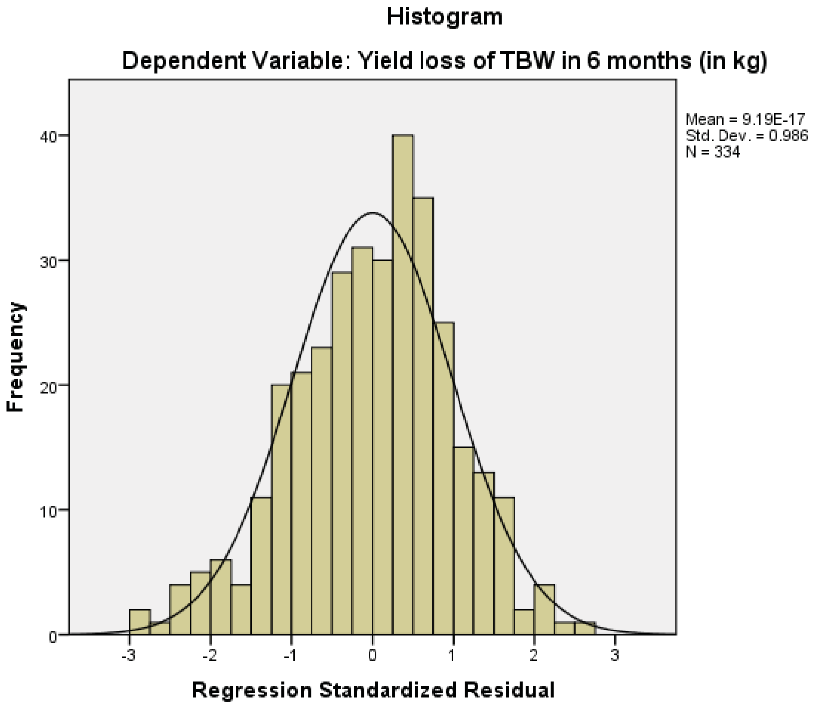

Fig. 1 Histogram of the standardized residuals

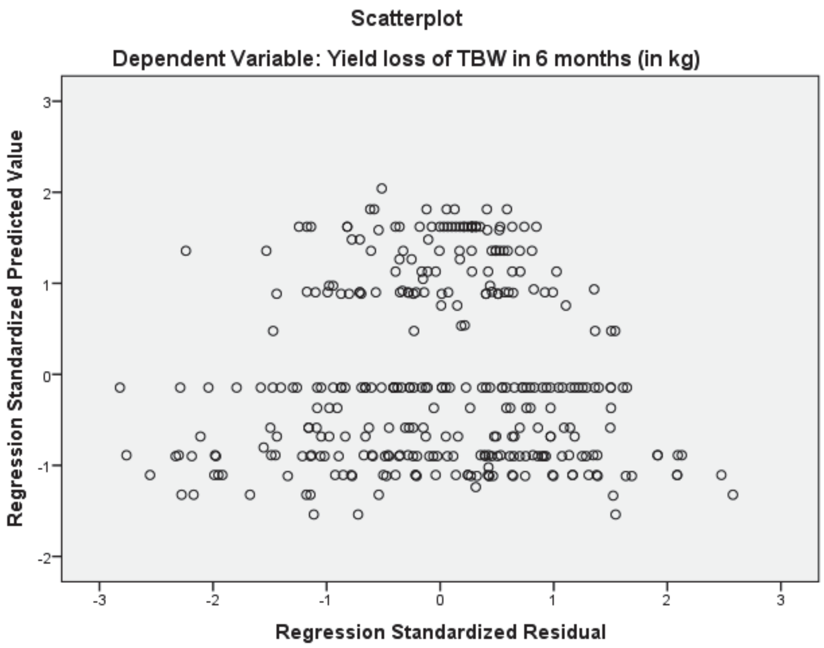

Fig. 2 Scatterplot of the standardized residuals

There were 16 out-of-sample palm were used to measure the predictive performance of the best model (i.e. Model 16). The value of MAPE as shown in Table VIII is 17.73% which is considered as a good forecasting [10].

IV. Economic Loss

The economic loss was estimated by using Model 16. The estimation was based on 216 infected palms (see Table I) with different disease severity and the current monthly price of fresh fruit bunch at mill gate in the state of Sabah which is RM0.44 per kilogram [13]. It was assumed that the potential yield of each of the palms is 80 kg as shown in Table II. Based on this figure, it was estimated that the total potential yield of these 216 palms if no disease infection is 17,280 kg or equivalent to RM7603.20. But due to the disease, the estimated economic loss of these infected palms is RM3293.50 in six months or 43.32% of the potential yields. It is clear that *Ganoderma* disease could cause a significant economic loss to the planters if no treatment or control measure applied.

TABLE VIII
MAPE OF THE BEST YIELD LOSS MODEL

Palm ID	Study site	A_i	F_i	Error
1692	MBE0702	-38	26.76	1.70
41	SKE0224	-57	44.11	1.77
63	SKE0224	-53	35.87	1.68
91	SKE0224	-35	35.87	2.02
655	SKE0224	-31	35.87	2.16
520	SKE0224	55	2.71	0.95
244	SKE0224	60	7.56	0.87
248	SKE0224	-1	-4.28	-3.28
156	SKE0224	2	0.58	0.71
243	SKE0224	3	-4.28	2.43
527	MAD8718	-82	12.58	1.15
962	MAD8718	58	12.58	0.78
307	MAD8718	61	41.08	0.33
636	MAD8718	61	41.08	0.33
46	MAD8718	66	12.58	0.81
807	MAD8718	1	12.58	-11.58
	MAPE			0.1773

TABLE IX
ECONOMIC LOSS

Disease severity	No. of palms	FFB loss (in kg)	Economic loss (in RM)	% of economic loss
R2	61	676.34	297.59	3.91
R3	86	3478.66	1530.61	20.13
R4	69	3329.82	1465.12	19.27
Total	**216**	**7485.23**	**3293.50**	**43.32**

V. CONCLUSION

The economic loss which was estimated by Model 16 has shown that *Ganoderma* disease causes a serious loss to the planters. The model developed in this study can be used by the oil palm planters to estimate their yield or economic loss due to *Ganoderma* incidence. By knowing the predicted yield loss, it surely helps the planters to identify the best solution to manage the disease in order to minimize their losses.

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