Geostatistics of Oil Palm Trees Affected by *Ganoderma* Disease in Low and High Planting Density

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**Abstract.** This study was conducted to assess the influence of two oil palm planting density (PD) on the incidence and severity of the *Ganoderma* basal stem rot (BSR) disease in oil palm planted in a plantation at Bagan Datuk, Perak, Malaysia. Ground surveys were conducted in oil palm planted in two planting densities involved which are: 120 palms/ha (lowest PD) and 200 palms/ha (highest PD) to assess the incidence and severity of BSR disease in oil palm plantations, over the 25 years after planting, YAP. The presence of the BSR disease symptoms as visually assigned followed the Standard Operating Procedures (SOP) Guidelines for Managing *Ganoderma* Disease in Oil Palm. Semivariogram analysis was performed on the data to show the spatiotemporal structure of BSR disease at 10, 15, 20 and 25 years after planting. The disease incidence was observed in all both plots with 0.57% to 1.67% at 8 years after planting, followed by increased to 15.12% to 38.3% at 16 years after planting. At 25 years, high BSR disease incidence was recorded on 200 palms/ha (72.5%), whilst low BSR disease incidence was recorded on 120 palms/ha. Effects of nugget to sill were found relatively moderate to weak of spatial pattern distribution. The observed disease patterns suggest that the progress of BSR disease incidence is firstly randomly scattered (8 to 10 years after planting) and secondly by root-to-root contact of the disease spreading to neighbouring palms may be occurred. Further study is needed to investigate factors associated with the outbreak of BSR disease in these plantations.

**Keywords:** geostatistics, oil palm, *Ganoderma* disease, planting density

1. **Introduction**

The basal stem rot (BSR) or *Ganoderma* disease was first reported since 1930 in Malaysia [1]. The main disease that threaten oil palm and caused significant economic loss is basal stem rot (BSR) or *Ganoderma* disease [2]. Survey on year 2010, BSR disease incidence in oil palm estates was 3.71% with 59,148 ha of the disease affected area [3]. Addressing status of the disease in oil palm has been increasing to 221,000 ha in 2017 [4]. The BSR disease cause by fungus *Ganoderma* species, mostly *G. boninense* [5]. This disease found mostly in Malaysia and Indonesia. Updating status of the disease were reported and comprehensively studies were carried out in oil palm [4 - 13].

Seriousness of the BSR disease has affected significantly on declining productivity in oil palm (OP). There are about 30%-40% of BSR diseased oil palm during twelve-years after planting (YAP) and more than 50% diseased oil palm at twenty-five YAP [8, 14]. It was reported that 10% loss of oil palm stand resulted in reduction of 0.16 t ha⁻¹ of FFB per additional palm death while 50% oil palm mortality resulted around 35% yield loss [14]. To improve the yield per hectare, variable planting densities (PD)
were suggested to design plantation at optimum palms per hectare [15]. The higher PD was suggested to achieve high OP yield production to 6-8 tonnes ha\(^{-1}\) [16]. However, devastating of the pest and disease attack in oil palm was affected on the yield reduction over the years of plantings [17].

Due to the emergent of the new industrial revolution, many countries have initiated comprehensive national plan towards Fourth Industrial Revolution (IR4). In 2018, Malaysia has launched the National Policy on Industry 4.0 (Industry4WRD) to increase competitiveness and encourage development of innovative capacity and capability of industrial and related services involving in the new technologies, products and services [18]. Malaysia is currently contributing for 28% of world palm oil production and 33% of world exports [19]. The implementation of advanced technologies in oil palm have becoming a reliable concept of digitalization plantations including advancements in genomics-based technologies has facilitating and improved the production of new breeding lines for oil palm for the industry [20].

BSR disease outbreak in oil palm naturally infected by *Ganoderma* could be monitoring as surveillance systems using geostatistical analysis. Geostatistical approach, originally developed for use in big data mining also to gain reliability of artificial intelligence, have also been applying in plant pathology to quantitatively characterize the spatial pattern of disease or a pathogen population in space over time [21, 22]. The study of spatial and temporal patterns can provide quantitative information on population dynamics, aid in the design epidemiological studies and of sampling programs for *Ganoderma* disease or pathogen monitoring, and useful to generate hypotheses about underlying ecological processes. Therefore, this study aims to determine and analyse the significant factors that influence *Ganoderma* disease incidence in oil palm area over time. The research findings are novelty input for development of GIS geodatabase for predictive modelling on the BSR disease in oil palm, thus suggesting the suitable method in controlling BSR disease.

2. Materials and Method

2.1 Study Area

This study was conducted at oil palm plantation in Bagan Datuk, Perak located in West Peninsular of Malaysia. The oil palm planted as first generation, applied as hole-in-hole planting technique, covered with top soils to remains the palms standing in the soil. The soil is characterized as peat soils, low bulk density, low pH level and comprised of decomposed organic matter that has accumulated in water-saturated land area.

![Study Area at West Peninsular of Malaysia.](image)
2.2 Ground survey of BSR disease

Ground surveys were conducted in oil palm plantation at 120 palms/ha (lowest PD) and 200 palms/ha (highest PD). The presence of the BSR disease symptoms as visually assigned followed the Standard Operating Procedures (SOP) Guidelines for Managing *Ganoderma* Disease in Oil Palm [23]. The oil palm census was classified based on visual symptom (Table 1). The BSR disease infected oil palm were confirmed using *Ganoderma* Selective Medium (GSM).

| Classification | Visual Symptom | Descriptions |
|----------------|----------------|--------------|
| Healthy        | Uninfected palm (Healthy), no fruiting bodies, foliar symptom and stem rotting at the base. No presence of *Ganoderma* using GSM method (negative). |
| Infected       | Infected palm (dead), presence of white mycelium or fruiting bodies for example small white button or bracket shape form. Palm dead showing severe foliar symptoms and stem rotting at the base. Confirmed presence of *Ganoderma* fungus using GSM method (positive). |

Note: Ground census was conducted based on presence and absence of the *Ganoderma* disease incidence in oil palm planted in the plantation.

2.3 Data Processing and Analysis

After the ground census have been conducted, data acquisition from the field oil palm plantations were digitized in Geographical Information System (GIS) software, ArcGIS Desktop v10.3.1 for further analysis process. As initial, BSR disease attribution from the plot A and B were interpolated using Spatial Analyst Tools > Interpolation > Kriging techniques. This is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. Unlike other interpolation methods, this tool is effectively involves an interactive investigation of the spatial behaviour of the phenomenon represented by the z-values before selection the best estimation method for generating the output surface [24]. Then, Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. The Kriging tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. Kriging is a multistep process; it includes exploratory statistical analysis of the data, variogram modelling, creating the surface, and (optionally) exploring a variance surface. Kriging is most appropriate when we know there is a spatially correlated distance or directional bias in the data. It is often used in soil science and geology [24].

After that, GS+ software was used to conduct semivariogram analysis to calculate the spatial structure and dependence of the disease incidences. Semivariogram is characterisation of spatial autocorrelation. Autocorrelation is correlation between elements of a series and others from the same series separated from them by determined interval. Two fundamentals involved to this analysis are to defined the fitted model of based on uncertainty parameters of the estimated surface and to describe spatial pattern by interpolating the sampled values. From the analysis, the fitted semivariogram models provide information about the spatial structure as well as the spatial attributes for the data interpolation. The models can be described by three parameters: 1) nugget, the measure of the amount of variance; 2) sill, the total vertical scale of variogram and often approximately equals to the sample variance; and 3) range, the distance or diameter of influence where two samples are related [25,26]. Several models such as gaussian, spherical, linear and exponential can be fitted to estimate semivariogram to determine the spatial structure of the disease distribution. In that analysis, the semivariance $\lambda(h)$ is estimated by
calculating the mean of the squared differences between values of pairs of samples for a given lag distance \( (h) \) \[27\]:

\[
\lambda(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2
\]

(1)

Where; \( \lambda(h) \) is the number of data pairs separated by a specific distance \( h \) (the lag), and \([z(x_i) - z(x_i + h)]\) is the change of the attribute \( z \) from one point to the next point, whereby the distance between these points is \( h \).

Then, the BSR disease incidence in plots A and B have been described spatially using spatial dependence values. In addition, the spatial relationship among neighbouring observations of the variables were assessed using autocorrelation analysis. The variogram is a graph of semivariance vs. separation distance. Where autocorrelation is present, semivariance is lower at smaller separation distances (autocorrelation is greater). This typically yields a curve such as that described below, which can be modelled using three terms – a nugget variance, a sill, and a range which are provided in GS+.

There are four types of isotropic variogram models are provided in GS+ which are Linear, Spherical, Exponential and Gaussian models. Each of model can be described using the terms as follows such the Nugget variance \((Co)\) – the y-intercept of the model; Sill \((Co+C)\) – the model asymptote; and Range \((A)\) – the separation distance over which spatial dependence is apparent.

3. Results and Discussion

3.1 BSR disease incidence

The BSR disease incidence was recorded in two different plots of planting density (PD) as summarize presented in Figures 2 and 3 based on visually symptoms (Table 2). Total oil palms involved for oil palm disease assessment in that studied area were 529 (lowest PD, 120 palms/ha) and 600 (highest PD, 200 palms/ha). At the 10 years after planting (YAP), only 2.46% of BSR disease incidence were recorded in lowest PD compared with the highest PD (8.8%). After 25 YAP, the highest BSR disease incidence was recorded in the highest PD (200 palms/ha) probably related with the planting distance of palms were adjacently planted in the plantation. In fact that, the oil palm planting densities have contributed as one of the abiotic factors that related with BSR disease infection. Remains of infected stump oil palm debris had found as the reasonable source of Ganoderma disease were attacked in new oil palm after replanting [6]. The root contact mechanism with unattended infected debris left in the plantations during replanting is known to be the primary source of infection spread [28].

![Figure 2. BSR disease incidence over the time in oil palm planting density 120 palms/ha.](Image)
From results observed, BSR disease incidence was recorded up to 72.5% in highest PD, whilst about 42.5% in lowest PD. It was reported that the BSR disease incidence was typically about 1% - 2% in 15 until 20 YAP, whereas it could increase up to 25% of the disease incidence at 25 years after plantings [14]. Furthermore, the status of BSR disease incidence in oil palm estates has increasing over the years from 3.71% (59,148 ha) to 7.4% (221,000 ha) [4].

![Figure 3. BSR disease incidence over the time in oil palm planting density 200 palms/ha.](image)

### 3.2 BSR disease distribution analysis

After the ground census have been conducted, BSR disease assessment data acquisition from the field oil palm plantations were digitized as input attributes in Geographical Information System (GIS) software, ArcGIS Desktop 10.3.1 for data processing. As initial, BSR disease attribution from the plot A and B were interpolated using Spatial Analyst Tools > Interpolation > Kriging techniques. The BSR incidence points were interpolated using kriging method fitted a model of semivariogram that can gave the best coefficient of determination ($R^2$) [29, 30]. At 10 YAP, BSR disease were recorded at 2.46% of the disease incidence in plot A (lowest PD) with total infected recorded was 13 palms trees and 8.83% of the disease incidence in plot B (highest PD) with total infected recorded was 53 palms trees. At 15 YAP, the disease was increased in both plots at 12.67% in plot A and 32.0% in plot B.

BSR disease incidence has been recorded most in two consecutive years of plantings which are at 20 YAP and 25 YAP, the BSR incidence 26.7% - 41.59% (plot A) and 64.5% - 72.5% (plot B) respectively. As fact, overall distribution of BSR disease incidence in plot A and B was initially randomly clustered at 10 YAP, whilst it was random distributed after the 15 YAP and remained as it was until 25 YAP. It was suggested that all palm trees had same probability of affecting to the disease in oil palm plantations as mentioned earlier by [10, 12, 25-27].

Based on our study, results of Kriging interpolations has significan tly observed to correlate the effects of planting distance in oil palms or directly knowns as planting densities (PD) which could be determined the BSR disease infection in oil palm plantations. These results have been suggested the direction between sample points (oil palm trees) might reflects on BSR disease incidence at different planting density of difference plots in plantations as presented (Table 2).

### 3.3 Geostatistical analysis

In order to evaluate the spatial dependence, three classes of spatial dependence for BSR disease were calculated based on the proportions of nugget ($C_0$) over the sill ($C_0+C$), either it was considered strongly spatial dependent at <$0.25 (<25\%$); moderate spatial dependence in range between of 0.25 and 0.75 ($>25\%$ and $<75\%$); and weakly spatial dependent at $>0.75 (>75\%)$. The spatial relationship among
neighbouring observations of the variables were assessed using autocorrelation analysis corresponds to the isotropic variograms model (Table 3).

**Table 2.** BSR disease incidence from oil palm in different planting densities using kriging at 10, 15, 20 and 25 years after planting.

| Plot | Year after planting (YAP) |  |  |
|------|---------------------------|---|---|
| A (PD 120 palms/ha) | 10 | 15 | 20 | 25 |
| | Exponential | 0.0044 | 0.0257 | 0.829 | 11.1 | 0.162 |
| | Exponential | 0.0084 | 0.1138 | 0.926 | 11.8 | 0.225 |
| | Exponential | 0.0178 | 0.1916 | 0.907 | 9.6 | 0.319 |
| | Exponential | 0.0240 | 0.2420 | 0.901 | 18.0 | 0.890 |
| B (PD 200 palms/ha) | 10 | 15 | 20 | 25 |
| | Exponential | 0.0143 | 0.0861 | 0.834 | 6.6 | 0.060 |
| | Exponential | 0.0396 | 0.2212 | 0.821 | 6.2 | 0.029 |
| | Exponential | 0.0275 | 0.249 | 0.890 | 11.1 | 0.769 |
| | Exponential | 0.00313 | 0.01776 | 0.824 | 5.1 | 0.002 |

Note: Colour of map showed the severity of the BSR disease incidence as Red represents very high incidence, Orange Medium severe incidence, Yellow low incidence and Blue colour represents none incidence or none infected oil palm.

**Table 3.** Semivariograms models of BSR disease incidence from oil palm in different planting densities using spatial autocorrelation analysis at 10, 15, 20 and 25 YAP.

| Plots | Years | Model | Nugget 
(Co) | SV Sill 
(Co+C) | Ratio 
C/(Co+C) (%) | Range 
(m) | R² |
|-------|-------|-------|--------|-----------|-----------|--------|--------|
| A (PD 120 palms/ha) | 10 | Exponential | 0.0044 | 0.0257 | 0.829 | 11.1 | 0.162 |
| | 15 | Exponential | 0.0084 | 0.1138 | 0.926 | 11.8 | 0.225 |
| | 20 | Spherical | 0.0178 | 0.1916 | 0.907 | 9.6 | 0.319 |
| | 25 | Exponential | 0.0240 | 0.2420 | 0.901 | 18.0 | 0.890 |
| B (PD 200 palms/ha) | 10 | Exponential | 0.0143 | 0.0861 | 0.834 | 6.6 | 0.060 |
| | 15 | Gaussian | 0.0396 | 0.2212 | 0.821 | 6.2 | 0.029 |
| | 20 | Exponential | 0.0275 | 0.249 | 0.890 | 11.1 | 0.769 |
| | 25 | Exponential | 0.00313 | 0.01776 | 0.824 | 5.1 | 0.002 |

Note: Spatial dependence based on proportions of nugget 
(Co) over the sill 
(Co+C).

In this study, the semivariograms (SV) were fitted to the model that gave the best coefficient of determination (R²). These models were then validate through the relation factor (PD), from the results it has determined that plot A has spatial dependence varied from 0.829 to 0.926 (82.9% to 92.6%), while the plot B has recorded spatial dependence varied from 0.821 to 0.890 (82.1% to 89.0%). In this study, the spatial autocorrelation found to be relatively weak for all planting densities.

Semivariograms fitted mostly to exponential model and less fitted with spherical and Gaussian model (Table 2). In the plot A (lowest PD), the semi variance was calculated for all neighbouring palms trees
that are 9.6 m apart (smallest lag) after that the spatial range was calculated as between 11.1 and 18.0 m at a distance. While in the plot B (highest PD), the SV was calculated from the smallest lag of 5.1 m apart, then the BSR disease spatially located between 6.2 until 11.1 m apart from the main source of inoculum in the oil palm plantations.

This study indicates that the BSR disease incidence in oil palm PD 120 and 200 palms/ha distributed randomly throughout the plantation. A strong and moderate spatial dependence showed a high propensity for nearby locations to influence each other and to possess similar attributes [32]. This study observed that the effect of nugget to sill ratios were found relatively moderate to weak of spatial pattern distribution. The observed disease patterns suggest that the progress of BSR disease incidence is firstly randomly scattered (8 to 10 years after planting) and secondly by root-to-root contact of the disease spreading to neighbouring palms may be occurred [29].

4. Conclusion
As the conclusion, geostatistical analysis of BSR disease incidence were evaluated in two different plots to determine spatial and correlation of oil palm planting density with the disease development and spread in oil palm plantation. This study shows that the BSR disease incidence is significantly higher for oil palm plantation with high planting density compared to the lower density plantation. We found that evaluated oil palm plots in the difference planting densities have significant spatial correlation even it was weak dependence in relation with this predisposing factor. This study suggested, to investigate in others oil palm areas with others predisposing factors which is great importance for BSR disease control and management in oil palm plantations.

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