Assessment of Basal Stem Rot Disease Distribution in Palm Oil Plantation Using Geographical Information System

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Abstract

The concurrent advances in global positioning systems (GPS) and Geographical Information Systems (GIS) techniques have provided powerful analysis tools for precision agriculture. This study will focus on how Geographical Information System (GIS) can help to assess the distribution Basal Stem Rot Diseases (BSR) on oil palm plantation. Basal Stem Rot (BSR) is caused by Ganoderma Boninense, and it is the most serious disease for oil palm trees in Malaysia. The fungus infects oil palm trees, initially causing yield loss and finally killing the trees. Various factors were previously reported to influence incidence of BSR, such as previous crops, techniques for replanting, types of soils, density and the age of trees. At present, effective and sustainable management strategies to control BSR are hampered mainly by a lack of understanding of mechanisms of disease establishment, development and spread. The study aims to apply spatial analysis methods to investigate the behaviours of BSR. Data for analysis were obtained from oil palm plantation at Teluk Intan, Perak, Malaysia.

Keywords: geographical information system; palm oil; basal stem rot; spatial pattern; hotspots

1. INTRODUCTION

Malaysia currently accounts for 39% of world palm oil production. The country is now the second world's largest exporter of palm oil and become one of the world's leading palm oil producers, with 18.9 million tonnes of oil palm produced in 2011. However, a basidiomycete fungus, species of Ganoderma, which cause basal stem rot disease in oil palm [1], devastate thousands of hectares of plantings in Southeast Asia especially in Malaysia and Indonesia [2]. The disease has been found to infect oil palms as early as 12 to 24 months after planting, with increased incidence on 4 to 5 years old palms, particularly in replanted areas [3], or areas under planted with coconut palm trees [4]. The disease is presently the most prevalent and devastating disease in oil palm cultivation, especially in mature palm areas in Malaysia [5]. BSR can kill up to 80% of the stand by the time when the palms are halfway through their normal economic life span [1]. Recently, the International Workshop on Awareness, Detection and Control of Oil Palm Devastating Diseases in Kuala Lumpur, Malaysia has identified BSR disease as a single major devastating disease constraint to oil palm production in the region [6].

The study of spatial pattern and hotspots can provide quantitative information on BSR disease dynamics, develop more accurate sampling plants better assesses crop loss in relation in relation to disease intensity and design and analyze experiments more efficiently. Until today, limited studies has been done to investigate the spatial patterns of BSR and how BSR is distributed throughout the area of plantation. For these reasons, there is a need for an effective and comprehensive BSR management plan for the area of oil palm plantation.

The general objective of this study was to examine the distribution of Basal Stem Rot disease caused by Ganoderma Boninense in oil palm plantation. This objective can be divided into the following specific goals:

- To characterize the spatial pattern of BSR disease in oil palm plantation.
- To determine the influence of BSR disease incidence at one location on incidence at other locations.
- To determine where BSR disease hotspots if exist.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted at Teluk Intan Perak (3.49oN, 101.06oS), Peninsular Malaysia (Figure 1). The total experiment area is about 11.22 ha. The palms were planted in August 1985 using a hole-in-hole planting method. The study area is flat, receives a moderately high and uniformly distributed rainfall and has a high soil water table. The annual rainfall at the site varied from 1696 to 2404 mm with the driest month being July and the wettest, November [1].

The soil is characterized a very deep (above 3 metres) peat, comprised of heterogeneous mixture of more or less decomposed plant (humus) material that has accumulated in a water-saturated environment and in the absence of oxygen [1].Among the important inherent characteristics of the Malaysia peat land is the presence of a dense mass of woody materials, usually water-logged in its natural state, shrinkage and subsidence upon drainage, irreversible drying if excessively drained, extreme acidity and low fertility status [4]. Its structure ranges from more or less decomposed plant remains to a fine amorphic, colloidal mass [7]. The peat medium is a structureless material that has a very low bulk density, low in nutrients and low in pH level [8]. The site was previously a secondary peat forest.

Figure 1: Teluk Intan Perak, Malaysia

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2.2 Data Collection

Information on BSR disease incidences was obtained from a comprehensive monitoring program over a period of 20 years. Three main plots of palm oil densities were observed, Planting density A (120 palms/ha), Planting density B (160 palms/ha) and Planting density C (200 palms/ha) (Figure 2). The three palm oil densities represent a reasonable range that could be used commercially. The palms were arranged in an equi-triangular planting. Planting density A, and C were split into 28 sub-plots while planting density B was split into 23 sub-plots. Each sub-plot contained 19 to 25 oil palms. Planting density A, B and C were planted with a distance of 8.5 m x 8.5 m x 8.5 m, 9.8 m x 9.8 m x 9.8 m and 7.6 m x 7.6 m x 7.6 m for each tree respectively.

Census was carried out in August during each year where oil palms were visually recorded into two categories: healthy palm (0) and unhealthy palm (1). The distribution of the healthy and unhealthy palm oil was mapped using ArcMap of ArcGIS 9.2 (ESRI). Geographic locations of each palm are collected using GPS receiver. The GPS is a highly accurate satellite based radio navigation system providing three-dimensional positioning, velocity, and time information.

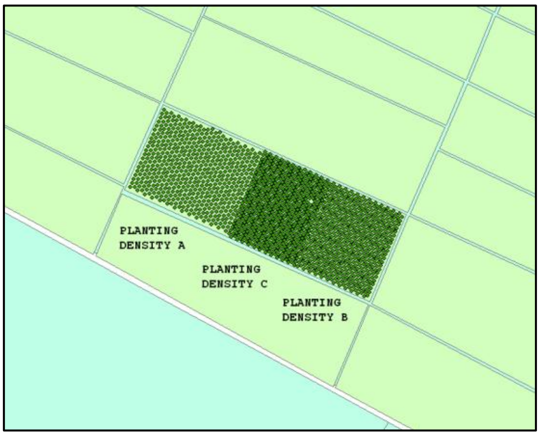


Figure 2: BSR incidences

The database includes several data layers like regional map, plantation map, road map, palm tree map and BSR incidences were created using Geographical Information System. The map is layered using the ArcMap of ArcGIS (9.2) software.

2.3 Spatial Pattern

A spatial autocorrelation analysis was performed on the field data. The empirical variogram provides a description of how data are correlated with distance or in other word it is a measure of the degree of spatial dependence between samples. The magnitude of the semi-variance between points depends on the distance between them. A smaller distance yields a smaller semi-variance and a larger distance results in larger one [6]. The semivariogram function (Figure 3), γ(h), is defined as half the average squared difference between points separated by a distance h [9] and is described as:

$$\gamma(h) = \frac{1}{2|N(h)|} \sum_{N(h)} (Z_i - Z_j)^2 \qquad (1)$$

where N(h) is the number of sample pairs at each distance interval h, and z_i and z_j are data values at spatial locations i and j, respectively. The letter h represents a distance measure with magnitude only but when direction also considered, it becomes a vector h [9].

The graph of γ(h) versus the corresponding values of h, called a semivariogram, is a function of the distance h and therefore, depends on distance magnitude and direction. A mathematical equation of the semivariogram is used to express the spatial dependence among samples to allow estimation of values for unsampled location. For properties that are spatially dependent, the increment $(Z_i - Z_j)$ is expected to increase with distance, up to some distance beyond which it stabilizes at a sill value $(C_0 + C)$, and is numerically almost equal to the variance of the data. This distance is called the range (a) and represents the radius of a circle within which the observations are correlated. The intercept to γ(h) axis is called nugget effect (C_0), and represents the variability at distances smaller than the minimum sampling distance.

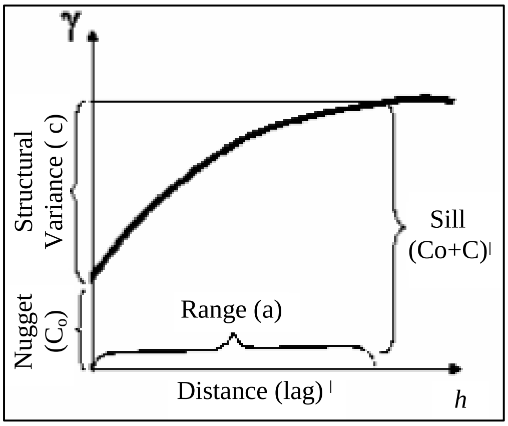


Figure 3: Schema of semivariogram used for analysis of spatial structure

In practice, the direction effect was considered by computing experimental variograms according to different directions of the h vector. The resulting graphs were compared, and no significant differences indicate that the field plot may be considered isotropic. In this study only isotropic models were considered. The spatial structure of the data is determined by fitting a mathematical model to the experimental semivariogram.The semivariogram analysis was performed using Geostatictical Analyst tool of ArcGIS.

2.3 Hotspots

In order to identify the areas that experienced high density of BSR diseases, hotspot analysis is conducted. Hotspot analysis is achieved by transforming the discrete point distribution of BSR diseases to a continuous surface of BSR disease density. For that purpose Kernel density estimation (KDE) technique is used [10].

KDE is an interpolation technique that generalizes individual point locations or events, s_i, to an entire area and provides density estimates, $\lambda(s)$, at any location within the study region R (Figure 4).

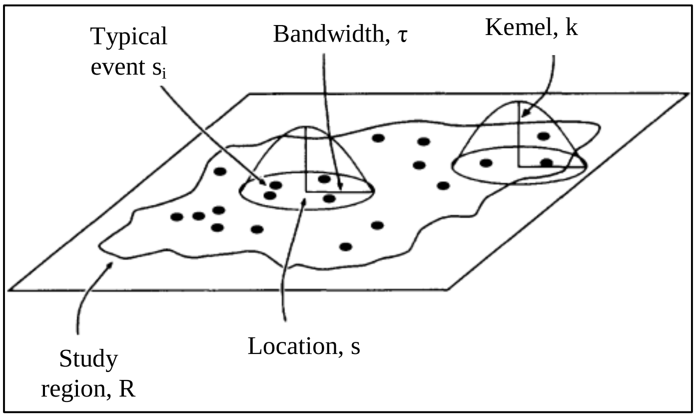


Figure 4: Kernel estimation of a point pattern

Distances to each observed event s_i that lies within a specified distance τ, referred to as the bandwidth, are measured and contribute to the intensity estimate at s according to how close they are to s [11]. This produces a more spatially smooth estimate of variation in $\lambda(s)$ than could be attained by using a fixed grid of quadrates. Formally, if s represents a vector location anywhere in R and $s_1, \ldots, s_n$ are the vector locations of the n observed events, then the intensity, $\lambda(s)$, at s is estimated as

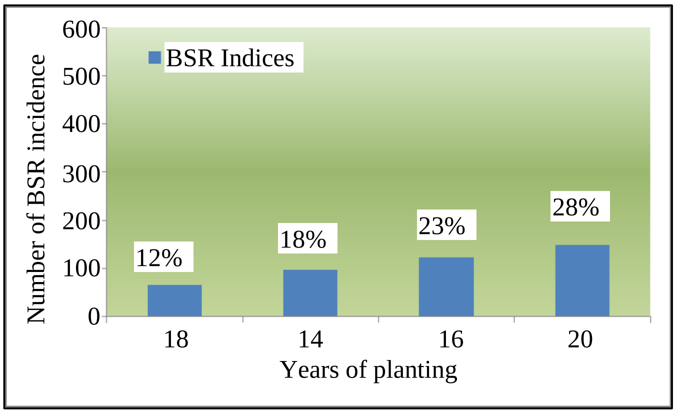
$$\hat{\lambda}(s) = \sum \frac{1}{\tau^2} k\left(\frac{s - s_i}{\tau}\right) \tag{2}$$

Where, $k()$ represents the kernel weighting function which for convenience is expressed in standardized form.

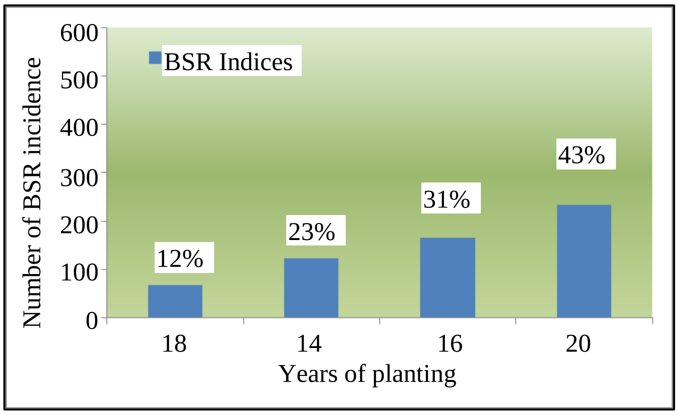
3. EXPERIMENTAL RESULTS

3.1 BSR Incidence

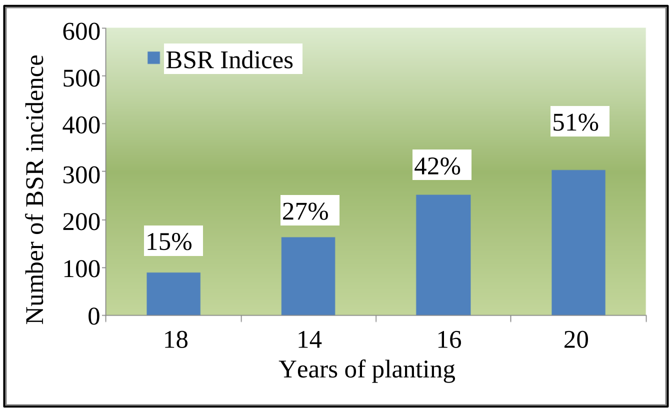
The summary of BSR disease incidence in the study area is presented in Figure 5. After fourteen years of planting, in Plantation A and B only 12% of oil palms were affected by BSR disease. While in Plantation C, it was found that 15% were affected by the disease. At 20 years after planting, 28%, 43%, and 51% of BSR incidences were found in plantations A, B, and C, respectively. Planting density C was infected greatly by BSR disease due to the plantation was being planted very near to each other. Unlike plantation A and B which had a moderate distance that reduced the probability of BSR disease. From the observations of the three planting densities, the distance between each palm trees was significant as one of the main factors contributing to BSR disease infection.



Plantation A



Plantation B



Plantation C

Figure 5: BSR incidence (%) in oil palm at plantations A, B and C

3.2 Spatial Autocorrelation

In order to evaluate the spatial dependence, three classes of spatial dependence for BSR diseases were calculated based on the ratio of nugget (C0) to the sill (C0+C) [12]. If the spatial class ratio was < 25% the variable was considered strongly spatially dependent; if the ratio was > 25% and < 75%, the variable was considered moderately spatially dependent; and if the ratio was >75%, the variable was considered weakly spatially dependent [12]. All the result presented corresponds to the isotropic variogram.

In this study, each palm tree is coded either 1 or 0 to indicate the presence or absence of BSR disease (healthy) status then z can only be 1 or 0 and the change of z from one tree to its neighboring tree is either 0 if both trees are the same or 1 if the trees differ with respect to their BSR disease status. For plantation A (120 palms/Ha), the semi variance will be calculated for all trees that are 9.8 m apart (smallest lag) after that for all trees that are 19.6 m apart and so on. While for plantation B (160 palms/Ha), the semi variance will be calculated from the smallest lag of 8.5 m, then 17 m and so on. Meanwhile for plantation C (200 palms/Ha), the semivariogram will be calculated from the smallest lag of 7.6 m, then 15.2 m and so on.

Table 1 presents summaries of variogram for plantations A, B and C. All the semivariograms were fitted to the spherical model. There was a strong indication that the BSR disease in planting density A, B, and C were initially randomly distributed throughout the plantation.

The parameters of semivariograms were fitted according to the model that gave the best coefficient of determination (R2). These model were then validate through the relation , in which we can see that for this BSR disease, this index varied from 49.93% to 100%, 95.67% to 100%, and 93.47% to 100% for plantations A, B and respectively (Table 1). From the result, the spatial autocorrelation found to be relatively weak for all plantation densities. The result shows that the phenomenon being studied is tending towards randomness, with no relation between samples.

Table 1: A Summary of semivariogram model of BSR incidencein palm oil at Plantation A, B and C

Plantation	Years	Nugget (C0)	SV (C)	C0/(C0+C) (%)	Range (m)
A	14	0.21737	0.032575	86.97	93.433
	16	0.11850	0.118810	49.93	15.911
	18	0.14142	0.000119	99.92	62.209
	20	0.20188	0.000000	100.00	259.341
B	14	0.10889	0.000000	100.00	225.115
	16	0.17098	0.007666	95.71	235.062
	18	0.20811	0.009420	95.67	235.062
	20	0.23603	0.001083	99.54	84.270
C	14	0.12772	0.000000	100.00	226.489
	16	0.19204	0.006325	96.81	41.436
	18	0.22817	0.015953	93.47	38.743
	20	0.23586	0.014937	94.04	41.424

3.3 Hotspots

Smoothing of the entire area is performed using kernel estimation as an interpolator. A ratio of the density estimate of BSR disease incidences to the density estimate of total disease population was obtained and mapped through interpolation method. Figure 4 shows the density map that was created to delineate the precise locations and spatial extent of gastroenteritis clusters in the dataset.

The Figure 6 showed that red colour represents high risk areas and green colour represents low risk area of the disease. Fourteen (14) years after planting, spreading of BSR disease start with 65 palms or 12% infected in plantation A, 67 palms or 126% infected in plantation B and 90 palms or 15% infected in plantation C. Six years later (20 years after planting), percentage of the infected palm was increased to 28%, 43% and 51% respectively with more hotspots appeared and covered almost all the plantation especially in plantation C. The result showed that, the first fourteen years after planting, the spread of BSR were completely random. Sixteen years after planting, root contact of infection began to take place. At 20 years after planting, the infection mostly happened through root contact although the random spreads continuously happen in minimum cases.

Overall distribution of BSR disease incidence in plantation A, B, and C was initially random after fourteen year of planting and remained as it was until twenty years of planting. This means that all palm trees had a same probability of developing the BSR disease. In planting density C, the increase in BSR incidence was very rapid compared to planting density A, or B, and almost half of plantation C area is affected by BSR disease in only a period of six years (Figure 6). Although the finding shows that the distribution of BSR was random but the result indicates that in higher density plantation, the probability of developing the BSR disease was higher compare to lower density plantation.

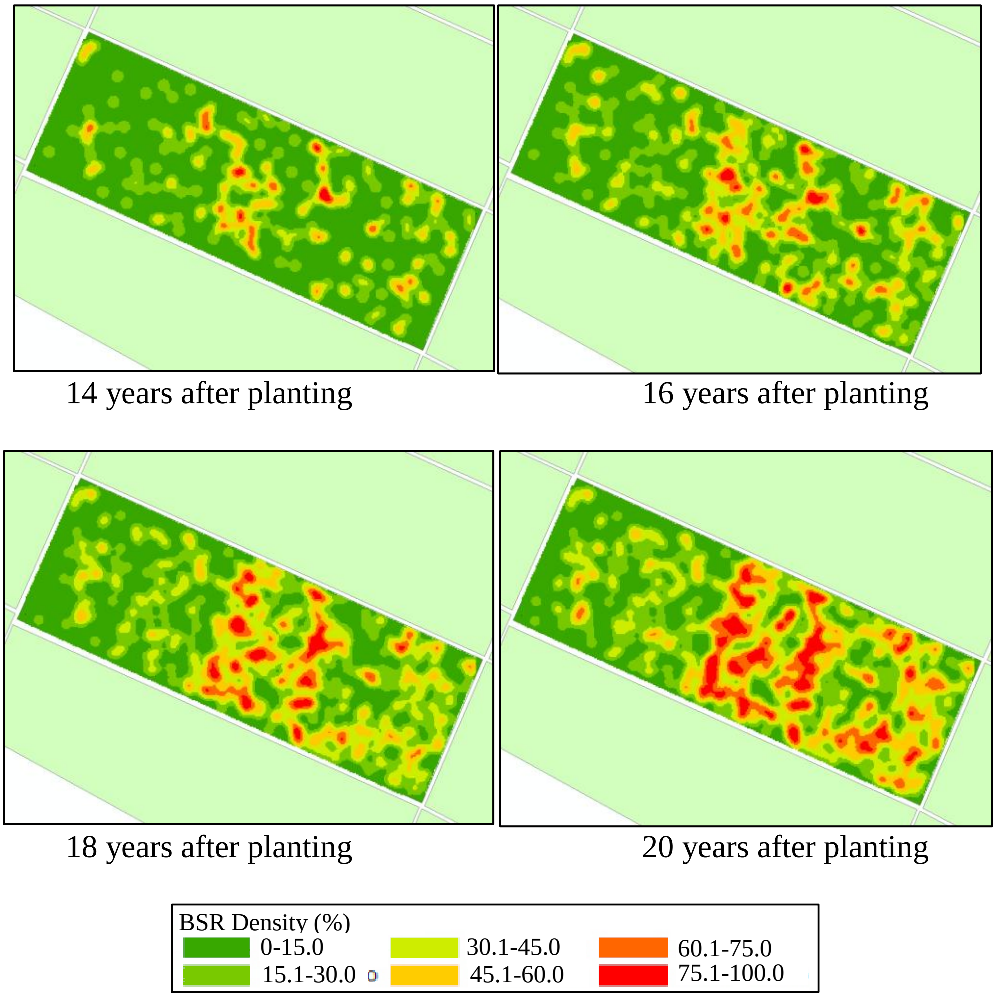


Figure 6: Hotspots analysis of BSR disease at plantations A, B and C

4. CONCLUSION

To summarize, the BSR disease distribution was random throughout the four years of observation in planting density A, B and C. Therefore, based on this preliminary analysis we concluded that the distribution of BSR disease was not associated with oil palm density condition. This study also shows that the distribution of the BSR disease incidence is far higher for the plantation field with a higher density of palm trees compared to palm trees that were in lower density plantation. The occurrence of

BSR disease is not a function of an infection from tree to tree, but a function of the disease pressure in the area.

The ability to develop good temporal modeling and prediction of BSR disease will allow a better planning for actions required to eliminate factors that may cause the development of basal stem rot disease. The knowledge of spatial temporal pattern of BSR disease is useful for making management decisions, especially for application of site-specific management as in precision agriculture. If a section of the field where the pathogen survives is identified and the pathogen density is quantified, there is no need to apply pesticide on the entire field.

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