Songklanakarin J. Sci. Technol.
38 (1), 23-30, Jan. - Feb. 2016

http://www.sjst.psu.ac.th

Original Article

Determination and mapping of calcium and magnesium contents using geostatistical techniques in oil palm plantation related to basal stem rot disease

Nur Shuhada Tajudin[1]*, Mohamed M. Hanafi[2], Abu Seman Idris[3], and Siva Kumar Balasundram[4]

[1] *Kulliyyah of Science, International Islamic University Malaysia, Kuantan, Pahang, 25200 Malaysia.*

[2] *Laboratory of Plantation Crops, Institute of Tropical Agriculture, Universiti Putra Malaysia, Serdang, Selangor, 43400 Malaysia.*

[3] *GanoDROP Unit, Biology Research Division, Malaysian Palm Oil Board, No. 6, Persiaran Institusi, Bandar Baru Bangi, Kajang, Selangor,43000 Malaysia.*

[4] *Department of Agriculture Technology, Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Selangor, 43400 Malaysia.*

Received: 8 January 2015; Accepted: 4 August 2015

Abstract

The basal stem rot (BSR) disease has been reported as the most destructive disease of oil palms in Southeast Asia. Adequate contents of nutrient in soil and leaf helps improve the plant health and its productivity. This study aims to determine the spatial variability of calcium (Ca) and magnesium (Mg) in soil and leaf collected in BSR infected oil palm plantation. The exchangeable calcium (Ca_{ex}) and magnesium (Mg_{ex}) in soil were found low in the study area ranged from 0.03-0.50% and 0.06-0.35%, respectively. The Ca and Mg content in leaf were also low ranged from 0.09-0.60%, and 0.03-1.87%, respectively. The Ca_{ex} in soil of both blocks showed a negative significant correlation with the disease at $p<0.01$. However, only Ca content in leaves of one study site (Block 2) showed a negative significant correlations with the disease ($p<0.05$). The generated map and significant correlations revealed that unbalanced nutrient content occurred in the study area.

Keywords: *Ganoderma*, oil palm, geostatistic, spatial variability, kriging

1. Introduction

The oil palm (*Elaeis Guineensis*) is the most important crop that produced approximately 39% of the world's vegetable oil supply (USDA, 2014). Among this, 30% of the world palm oil supplies are from Malaysia's plantation, which is about 5.23 million hectares in total (MPOB, 2013). However, one of the most devastating diseases in oil palm plantation in Southeast Asia is basal stem rot (BSR) disease caused by fungus of *Ganoderma* species. It is a root type disease, which infects the basal stem of the palm and restricts the transportation of water and nutrients to the upper parts of the palms. The disease has been recognized to infect oil palm as early as 12 to 24 months after planting and its incidence increased on 4 to 5 years old palms (Singh, 1991). Several factors have been identified to be associated with the disease, which includes age of palms, type of soil, nutrients status and previous crops planted in the area.

Nutrients in soil and leaves play important role in determining the health and disease resistance of the palm. In most situation, a balanced of nutrient in both soil and plant may improves the plants ability to disease resistance

* Corresponding author.
Email address: nurshuhada@iium.edu.my

(Usherwood, 1980; Fageria, 2009). The effects of nutrients to disease may be attributed to: (i) effects of nutrients on microclimate of the plants which can influence the plant growth and also affect infection and sporulation by the pathogen (Marschner, 1995), (ii) effects on the plants biochemical composition including the cell wall structure and tissues, (iii) effects on the pathogen through alteration in the soil environments, and (iv) the rate of growth of the host which may enable seedlings to escape infections in their most susceptible stage (Colhoun, 1973).

Calcium (Ca) is one of the most important nutrients that affect the susceptibility of the plant to disease in two ways. It is important for the cell wall stability, where Ca polygalacturonates were required to strengthen the middle lamella. It is also crucial for the function and stability of plant membranes. Deficiency of this nutrient leads to membrane leakage of low molecular weight compounds, such as sugars and amino acids. Thus, increased the potential of the fungi to invade the xylem and dissolve the cell walls of the conducting vessels and resulted to wilting symptoms. Application of soil Ca has been reported to protect peanuts pods from infections by *Rhizoctonia* and *Pythium* and eliminates the disease occurrence (Huber, 1980). In fact, increasing of Ca levels had reduced BSR infections (Nur Sabrina *et al*., 2012) due to improvements of the quality of the plants and prevention of favorable conditions for pathogens to inhabit. There is only little information on effects of magnesium (Mg) nutrition on plant disease (Dordas, 2008; Fageria *et al.,* 2011). Magnesium was reported to reduce the Ca content in peanut pods and may predispose them to pod breakdown by *Rhizoctonia* and *Pythium* (Huber, 1980).

Studies related to nutrients and the BSR disease were mostly conducted at the nursery stage and focusing on the molecular and genetic works only. Currently, there is limited information about nutrient spatial variability, such as Ca and Mg in oil palm plantation area and how its fertility factors can affect the disease distribution at the field scale. Inaccurate identifications of Ca and Mg status in large scale area leads to inaccurate fertilizing practice and results in wasting time and money. In order to manage and monitor Ca and Mg status of a large area, one of a better solution in helping the industry is by applying the geographical information system (GIS) technology. Therefore, this study was carried out to obtain accurate spatial distribution of the BSR disease, Ca and Mg variability by using GIS tools in oil palm plantation affected by BSR disease and to observe its correlation with the disease incidence.

2. Methods

2.1 Experimental site

The study was carried out in oil palm plantation area at Ladang Seberang Perak, Peninsular Malaysia (4°06'41.50" N, 100°53'05.71" E). In this study, two different plots of oil palm were selected to represent matured oil palm (Block 1) and young oil palm (Block 2) (Figure 1). Young and matured oil palm was planted in year of 2006 and 1994, respectively with planting density of 136 and 160 oil palm/ha. Block 1 is the first generation of oil palm planted, while the Block 2 is the second generations of oil palm. The study area is mainly composed of local alluvium soil of the Telemong Akob series. The soils of this study area were classified in the soil orders of Entisols and great groups of Typic Tropofluvents (USDA). This series were mainly dominated by local alluvial of mineral soil type. The mean annual rainfall is 1,500 mm with mean annual temperature of 29.8°C.

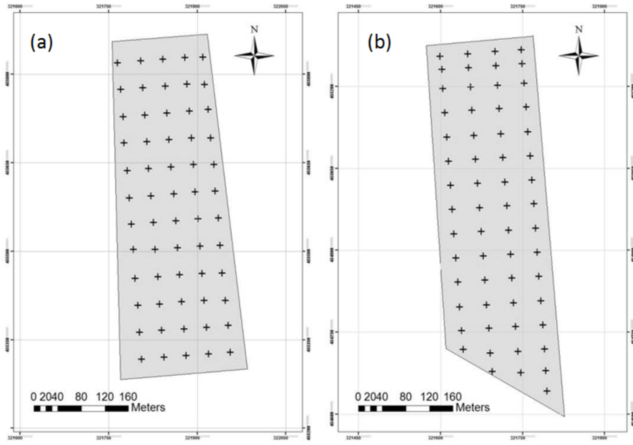

Figure 1. Study area and sampling point of Block 1(a) and Block 2(b).

2.2 BSR census

Information on BSR disease incidences were done through visual disease census in October, 2012. Coordinate of the study area and the sample collected were recorded using GPS. Standing oil palm was divided into two categories, which is "0" for healthy and "1" for trees that were confirmed infected by BSR disease. Oil palm infected by BSR disease was determined based on the appearance of multiple spear leaves, pale leaf canopy, presence of fruiting body at the stem base, and also a collapse of leaf canopy, while for healthy oil palm show a dark green leaves and a healthy leaves and stem. Ground census was done in young and matured palm plantation at the same time and season.

Distribution of BSR disease were then mapped based on the spatial point patterns, which represent the infected tress per ha area. The density map was performed using geostatistical tools of ArcGis 9.3 software. Each tree was projected and mapped using WGS 1984 UTM Zone. This technique shows a precise view of comparison among features by factoring impact of area across time. For the density estimation, the density value and categories were done based on value suggested by Singh *et al.* (1990) which describe that 30% of area affected by *Ganoderma* incidence in 1 ha of area had reduced 26% of oil palm fresh fruit bunch (FFB) yield (Table 1).

Table 1. BSR zone category based on losses of oil palm per hectare.

Losses of oil palm by BSR disease per hectare (%)	Number of trees infected	Category suggested
<15	<20	Very Low
30	21-40	Low
45	41-60	Medium
60	61-80	High
>75	>81	Very High

2.3 Soil samples

Soil samples were obtained systematically by grid sampling techniques consists of 60 geo-reference points in Blocks 1 and 2, respectively (Figure 1). Sampling points were spaced approximately 36 m in the X direction and 36 m in Y direction. Three composites samples (circle palm, between two palm and frond heap) were obtained at 0-20 cm depth from each sampling point. Soil samples were kept in a clean polyethylene bag and brought to lab for exchangeable Ca (Ca_{ex}) and exchangeable Mg (Mg_{ex}) content. The Ca_{ex} and Mg_{ex} were determined by neutral ammonium acetate extraction methods (Schollenberger and Simon, 1945). About 10 g of soil were leached with 100 ml of 1N ammonium acetate (NH_4OAc) using the leaching tube for 5-6 hours. The Ca_{ex} and Mg_{ex} in solutions was measured using atomic absorption spectrophotometer (AAS) (Perkin Elmer 400, USA). Evaluation of the Ca_{ex} and Mg_{ex} in soil were based on threshold value suggested by Goh and Chew (1997). Soil pH was determined using the glass electrode pH meter (Metler Toledo FE20, Switzerland) using soil: water ratio (1/2.5) (Hendershot *et al.,* 1993).

2.4 Leaves samples

Total of 60 leave samples were also collected at the same site of soil samples. Leaf samples were collected at the 17^{th} fronds of matured and young palm. The leaves were bulk together in a clean polyethylene bag and brought to the laboratory for further analyses. The middle 20 cm of the leaves were cut and retained for laboratory test of Ca and Mg. Leaflets were dried in air dried oven at 60-70°C for 2 days. Then, the samples were ground to pass through a 1 mm sieve size. A total weight of 0.25 g foliar tissue samples were digested on the hot plate with 5 ml of H_2SO_4 for 1 hour. Digested samples were then filtered and measures by AAS (Perkin Elmer 400, USA). Leaf Ca ad Mg contents were evaluated based on threshold value suggested by von Uexkull and Fairhust (1997).

2.5 Geostatistical analysis

The spatial structure of the soil and leaf nutrient within the study plots was analyzed using geostatistical software (GS^+, Gamma Design Software, St. Plainwell, MI, version 7.0). It offered numbers of models that can be fitted called semivariogram. In practice, this model used several authorized models (Oliver, 1987; Isaaks and Srivastava, 1989), such as linear (Lin.), spherical (Spher.), Gaussian (Gauss.) and Exponential (Exp.) model. These models were then fitted into the semivariogram data. Semivariance was estimated as follow:

$$\gamma(h) = 0.5\text{n(h)}\sum_{i=1}^{n(h)}\left[z_i - z_i + h\right]^2 \quad (1)$$

where, h is the separation distance between location X_i or X_{i+h}, or z_i or z_{i+h} are the measured values for regionalized variable at location xi or X_{i+h} and (h) is the number of pairs at any separation distance h.

A semivariogram, models the continuity of the spatial variable to a spatial structure. Spatial structure described several parameters, such as sill, nugget, and range and how the data were distributed in the study area. Spherical model is one of the most commonly used in the semivariogram model because of its linear behavior at small range which fit most experimental data (Isaaks and Srivastava, 1989). Models were selected based on the fitting of the data which more favorable weighted residual mean square and visual fit to the data at short lags. In this study, the process of selecting the sample interval, lag distance and semivariogram models were based on trials and error. However, the semivariogram in this study was constructed based on two criteria suggested by Journel and Huijbregts (1978) to guide the selection process, which includes, (i) Semivariogram should not include lag distances greater than half the maximum distance between two sampling points and (ii) Lag interval that was plotted was short to allow identification of the most suitable model to be fitted to the semivariogram.

The semivariogram was assumed to be isotropic and omnidirectional, which means that pairwise squared difference were averaged without regards to direction. Spatial dependence of each element was described using nugget to sill ratio (Table 2) (Cambardella *et al.*, 1994). A strong and moderate spatial dependence showed a high propensity for nearby locations to influence each other and to possess similar attributes (Goodchild, 1992). Weak or spatially uncorrelated spatial dependence is usually associated with sampling distances, analytical errors, and variation on shorter distance than applied sampling grid.

Table 2. Definition of spatial dependence.

Value (%)	Spatial dependence
<25	Strong spatial dependence
25-75	Moderate spatial dependence
>75	Weak spatial dependence

2.6 Correlations of Ca and Mg with disease incidence

The methods of calculating the incidence of BSR disease was by plot count data (Figure 2). Blocks 1 and 2 were divided into 60 units of cells, each approximately spaced 36 m in the X direction and 36 m in Y direction. Each cell consisted of 20 to 36 of oil palm trees. Data of tree identified to have a BSR disease was observed by a plot count and was represented by a percentage (%) of tree infected within a number of tree in that particular quadrat. The Pearson correlation method were used to correlate between % of the disease incidence and soil nutrient in each quadrat.

3. Results and Discussion

Distribution of BSR disease varied from very low to a very high risk of infected area (Figure 3). In 2012, Block 1 was dominated by moderate to a very high category of area infected by BSR disease. About 18% (1.9 ha) of area in this block was represented by a very high infected category and another 26% (2.73 ha) was area under high risk category. However, 94% of area in Block 2 was still dominated by very low and low categories of BSR infected area. Only 0.55% of the area in Block 2 was classified into a very high incidence of BSR disease area.

One of the sources that generate the disease to be spread in the study area was through the root contact with a source of inoculum. This could be from left inoculum of the alternative host plant or through root contact from infected oil palm (Chung, 2011). Since the matured oil palm had been planted about 15 to 20 years ago, the left buried of infected previous crops could have not been properly sanitized and this increased the potential of disease to be spread.

3.1 Descriptive statistic

Soil pH in the study area was categorized into acidic type of soil ranged from 3.05 to 5.85 (Table 3). The oil palm had the ability to tolerate acidic type of soil and capable to grow well under broad scale of pH ranged 4.0 to 5.5 (Goh and Chew, 1995a). Coefficient of variation (CV) described the behavior of the attributes within the study area. Higher value

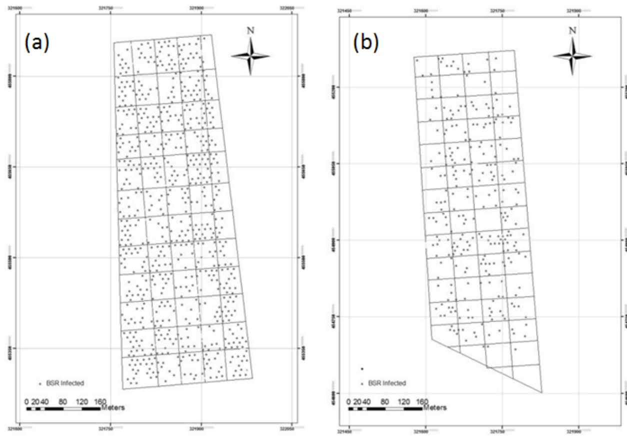

Figure 2. Distribution of BSR infected trees in unit cell of Block 1 (a) and 2(b).

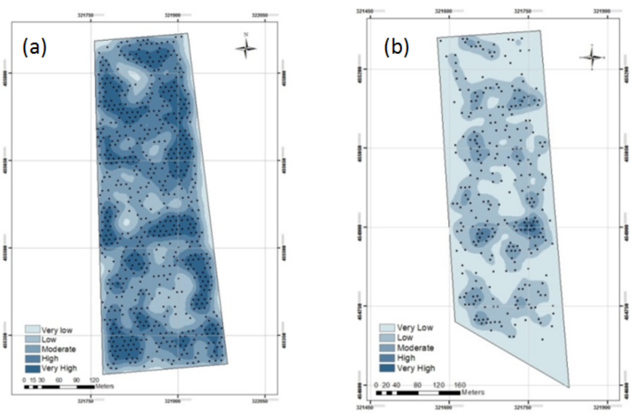

Figure 3. BSR densities in Block 1(a) and 2(b).

Table 3. Descriptive statistic of soil and leaf properties in Block 1 and 2.

Element	Mean		Std. Dev		Min		Max		CV%	
Soil	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
pH	4.30	4.41	0.40	0.39	3.05	3.25	5.85	5.85	9.30	8.84
Ca (%)	0.55	0.23	0.20	0.12	0.37	0.03	0.67	0.50	36.07	53.52
Mg (%)	0.31	0.23	0.25	0.23	0.09	0.03	1.87	1.54	82.70	99.11
					Leaf					
Ca (%)	0.15	0.29	0.05	0.09	0.09	0.10	0.32	0.60	33.33	31.03
Mg (%)	0.19	0.15	0.06	0.05	0.07	0.06	0.35	0.30	31.57	33.33

of CV reflects a higher variability of nutrients throughout the study area (Pimentel Gomez and Gracia, 2002). The CV of pH in the two blocks were found to be less than 10%, indicated that pH had the lowest variation throughout the study area compared to the content of Ca and Mg. Low pH variation described homogenous variability throughout the blocks. Other researcher had documented a lower variance of soil pH compared to other soil chemical properties (Yost *et al.,* 1982; Zhou *et al.,* 1998). This could be caused by the pH value which is on log scale of proton concentration in soil solution. There would be much higher variability in soil acidity if it is expressed in terms of proton concentration directly (Sun *et al.,* 2003). The CV of Ca and Mg in both soil and leaf were found to be more than 30% and were categorized to have a very high variability. It is well established that soil properties exhibits at high variability with CV often exceeding 30% and such variability has been shown to occur spatially and temporally (Webster, 1985; Goh *et al.,* 2000).

3.2 Geostatistical analysis

Semivariograms of Ca and Mg content in leaf and soil are given in Table 4. The Ca_{ex} and Mg_{ex} of soil in Block 1 showed a definable spatial structure described by a Gaussian model, while Block 2 was described by spherical model for both attributes. The best fitted model for Ca and Mg in leaf was exponential for both of the blocks. Low nugget variance in all of the blocks described that, only small errors occurred during sampling, measurement. Short effective range (<70 m) in almost all of the attributes in both blocks explained that, sampling point greater than this distance would no longer exhibit any spatial correlations (Balasundram *et al.,* 2008). The content of Ca and Mg in soil and leaf of Blocks 1 and 2 showed a strong spatial dependence, while only content of Mg in leaf of Block 1 showed a moderate dependence.

3.3 Spatial variability of Ca and Mg in soil and leaf tissue

The evaluation of Ca_{ex} and Mg_{ex} was made based on threshold value suggested by Goh and Chew (1997) for soil of oil palm plantation. The optimum of Ca and Mg in soil ranged from 0.75-1.00% and 0.20-0.25%, respectively. The content of Ca and Mg in leaf was evaluated based on von Uexkull and Fairhust (1991), which had been widely used for optimum oil palm growth. Optimum Ca and Mg content in leaf of oil palm ranged from 0.50-0.70% and 0.30-0.45%, respectively. Distributions of Ca_{ex} in soil of Block 1 showed a low to moderate content (0.50-0.70%), with about 84.30% of area were categorized within this ranged. Nevertheless, the young palms of Block 2 showed a lower content of Ca_{ex} with 81.70% of the area had a very low content of Ca_{ex} with value less than 0.30% (Figures 4a and 4c). The spatial distribution of Ca in leaf were also categorized as deficient, with 100% of area in both blocks had Ca content lower than 0.30 and 0.25% in Blocks 1 and 2, respectively (Figures 4b and d).

The content of Ca_{ex} in both blocks was observed low. Its availability in the soil environment had a significant relationship with the chemical condition of the soil including the pH. Soil pH is inversely related to Ca_{ex}. Acid soil is usually high in Al_{ex} but low in Ca_{ex} (Prasad and Power, 1997). A decrease in Ca_{ex} contents in soil is attributed to displacement by hydrogen ions, which can be originated from either acid depositions or uptake of cations by roots (Johnson *et al.,* 1999). Decline in deposition of Ca from the atmosphere may also contribute to decrease of soil Ca availability especially in acids soil. In this situation, additional Ca needs to be added to increase the availability of this element (Fageria, 2009). Soil towards higher pH would have more Ca and Mg for uptake of plants.

The Mg_{ex} in soil of Block 1 showed almost 41.84% of area in this block had low to moderate (0.20-0.25%) of its content, while another 29.41% of area was occupied by moderate to high (0.25-0.30%) content of Mg_{ex}. Block 2 showed a lower content of Mg_{ex} with 49.90% of area in this block was categorized into very low to low content of exchangeable Mg (Figures 5a and c). The Mg in leaf of both blocks showed most of the area in both blocks had a deficient content of Mg with value less than 0.20% (Figures 5b and d).

Most of the area in both blocks showed a lower content of Mg_{ex} than the moderate value suggested for oil palm growth. The Mg_{ex} was reported to decrease at oil palm circle and inter-rows area at two different depths. This is mainly due to high rate of NH_4^+ fertilizer and KCl fertilizer used in oil palm plantations (Ng *et al.,* 2011). The NH_4^+ and

Table 4. Parameters of theoretical semivariograms of soil properties in Block 1 and 2.

	Model		Nugget (C)		Sill (C_0)		Range (m)		R^2		Spatial Dependence (%)	
	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
					Soil							
Ca	Gauss.	Spher.	0.00001	0.0001	0.0018	0.017	39.50	61.90	0.60	0.65	0.56	0.59
Mg	Gauss.	Spher.	0.00001	0.0001	0.0223	0.017	41.50	61.90	0.64	0.65	0.04	0.59
					Leaf							
Ca	Exp.	Exp.	0.003	0.0006	0.08	0.008	32.30	5.50	0.55	0.03	3.48	8.07
Mg	Exp.	Exp.	0.003	0.03	0.008	0.15	585.60	26.80	0.76	0.57	40.8	19.55

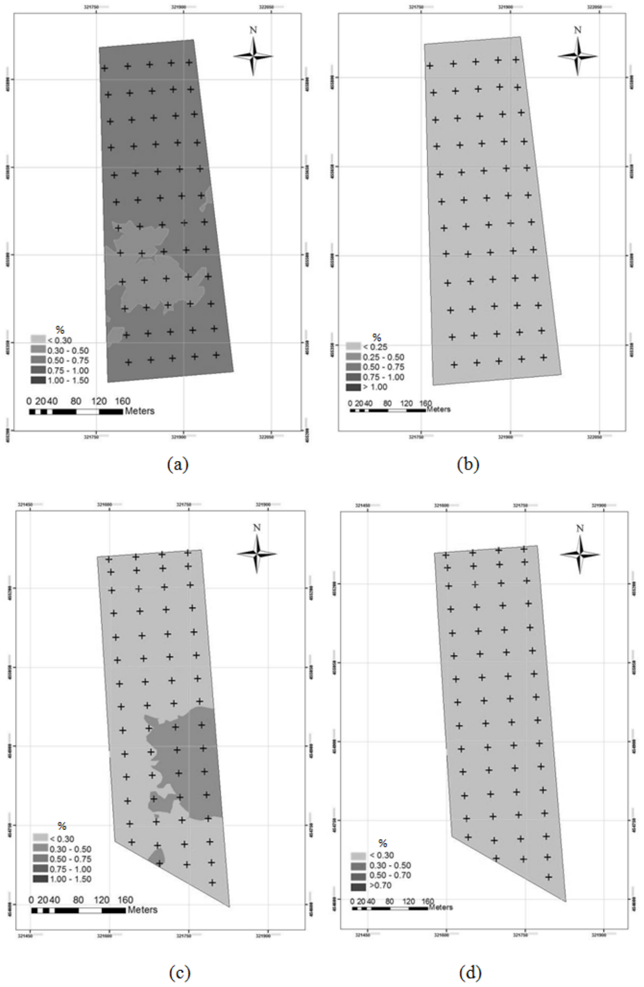

Figure 4. Spatial variability of Ca in soil (a and c) and leaf (b and d) of Block 1 and 2.

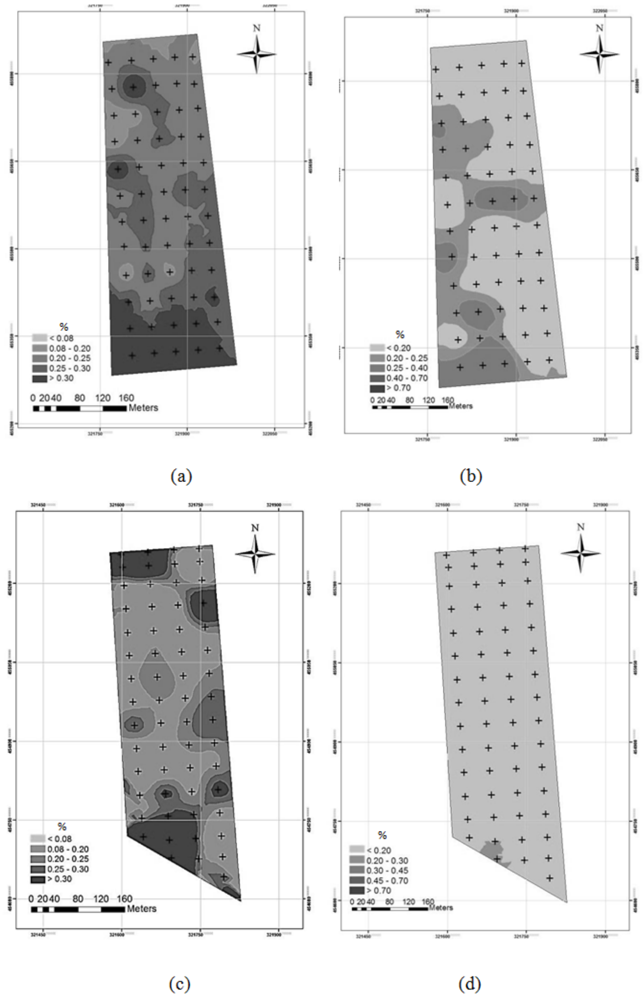

Figure 5. Spatial variability of Mg soil (a and c) and leaf (b and d) of Block 1 and 2.

K^+ cations caused the Mg in soil to leach down due to the ionic exchange between both cations in the soil complex (Kee *et al.,* 1995). This explained the lower content Mg_{ex} found in soil of this study area as excessive N (due to fertilizing) is believed to cause Mg to leach down as the soil samples were obtained at both oil palm circle and inter row.

Soil pH affects the availability of most nutrient elements for plants consumption. It also effects through the alteration of plants to resist the pathogens attacks. Lower pH value caused the amount of exchangeable aluminum (Al_{ex}) to increase and less Mg_{ex} was available (Brady and Weil, 2000). The availability of Mg^{2+} is slightly restricted and this explained the lower content of Mg found in this study site. Low to very low content of Mg_{ex} were also found in four from eight soil types commonly used for oil palm in Southeast Asia had soil pH less than 5.0 (Mutert *et al*., 1999) and this also explain the low contents of Mg within the study area. This suggest the needs of liming materials, such as calcitic limestone ($CaCO_3$) and dolomitic limestone ($CaMg(CO_3)_2$.

3.4 Correlations of Ca and Mg with disease incidence

In correlations of the disease with Ca and Mg content, Blocks 1 and 2 showed a significantly negative correlation between BSR disease and Ca_{ex} content in soil (Table 5). The correlation was observed to have only moderate and weak relationship in Blocks 1 ($p<0.01$) and 2 ($p<0.01$), respectively. However, only Ca in leaf of Block 2 showed a significantly negative correlation with only weak relationship ($p<0.05$).

Table 5. Correlation of Ca and Mg content in soil and leaf with BSR disease incidence (%) in Block 1 and 2.

BSR	Soil			Leaf	
	$Ca_{ex.}$	$Mg_{ex.}$	pH	Ca	Mg
Block 1	-0.56**	-0.23	-0.24	0.48	-0.16
Block 2	-0.45**	-0.10	-0.003	-0.49*	-0.03

Low content of Ca observed in both plants and soil in this study suggest that lack of Ca in those elements had impaired the structure and defense system of the oil palm. Calcium is important in the cell structure of plants. It prevents disease by providing a lignin barrier against pathogen attack (Williats *et al.,* 2001). In fact, Ca helps to harden the plant primary cell walls by cross linking of pectic polymers and confer resistance to pathogen attacks (Akai and Fukutomi, 1980). Insufficient of Ca content leads to deterioration of the cell membrane and caused the cells to become leaky. Deficiency of Ca increased the breakdown rates of cell wall by *Ganoderma* pathogens as it could attempts to breach and invade the plant cell (Nur Sabrina *et al.,* 2012).

The content of Ca in plants is important as it helps to reduce disease by slowing down the reactions of pathogenic enzymes reactions during the cells decomposition (Nur Sabrina *et al.,* 2012). Calcium also plays a role in improving the structure of the soil and also increasing the soil pH as these effects decreased the probability of *Ganoderma* pathogen to be attached (Nur Sabrina *et al.,* 2012). The Ca has significantly suppressed disease incidence of *Phytophtora* stem rot in soybean, which suggested that Ca is important in the cell wall as it could allow the tissue to maintain long term field resistance. This is linked to this study, where more Ca is needed to reduce the effects of the disease over a long time period. These effects will decrease the potential of *G. boninense* attachment (Nur Sabrina *et al.,* 2012).

The pH showed a negative but not significant correlation in both blocks (Table 5). The soil pH is well known to have influences on the development and severity of certain disease caused by soil borne organisms (Ycock, 1966). Such disease depends on the pH favors of the particular pathogen. It effects the growth and survival of pathogen, through competitive surviving of different microorganisms. Different ranges of pH vary for different pathogens over which they can grow. In general, acid soils are conducive to many diseases caused by fungi (Rengel, 2002) as this study area also was dominated by acidic type of soil. On the other hand, the club root of crucifers caused by *Plasmodiophora brassicae*, is most severe at the pH around 5.7. However, its development drops sharply between 5.7 and 6.2 and completely checked at pH 7.8. Further investigation need to be done in comparison of different soil pH to observe the effect of soil acidity on BSR disease.

4. Conclusions

Geostatistical techniques applied in this study demonstrated better methods of quantifying Ca and Mg variability throughout large scale oil palm plantations and are able to observe its relation with BSR occurrence. The content of Ca and Mg in soil and leaf were low in both blocks and this shows deficiencies of those elements within the study site. In relations to the BSR disease, significant negative correlations found between the disease and the content of Ca in soil and leaf explain that insufficient nutrients might alter the lignin compound, defense system and introduced favorable condition for the pathogens to invade. These combined data suggest the need of site specific approach in field management practice of oil palm plantation area in order to reduce BSR disease occurrence at the early stage of planting and thus conserve time and money.

Acknowledgements

The authors are grateful to Malaysian Palm Oil Board (MPOB) and FELCRA for logistical support and technical collaboration. Appreciation is also extended to International Islamic University Malaysia (IIUM) for the funding of this project.

References

Akai, S. and Fukutomi, M. 1980. Preformed internal physical barriers. In Plant Disease. An advanced treatise 5, Academic Press, New York, U.S.A., pp. 135-159.

Balasundram, S.K., Husni, M.H.O and Ahmed, O.H. 2008. Application of geostatistical tools to quantify spatial variability of selected soil chemical properties from a cultivated tropical peat. Journal of Agronomy. 7, 82-87.

Brady, N.C. and Weil, R.R. 2000. The nature and properties of soils. Fourteenth edition, Pearson Education, Singapore.

Cambardella, C.A., Moorman, T.B., Novak, J.M., Parkin, T.B., Karalan, D.L., Turco, R. F. and Konopka, A.E. 1994. Field scale variability of soil properties in central Iowa soils. Soil Science Society of America Journal. 58, 1501-1511.

Colhoun, J. 1973. Effects of environmental factors on plant disease. Annual Review of Phytopathology Journal. 11, 343-364.

Dordas, C. 2008. Role of nutrients in controlling plant diseases in sustainable agriculture: A review. Sustainable Development. 28, 33-46.

Fageria, N.K. 2009. The use of nutrients in crop plants, CRC Press, Boca Raton, New York, U.S.A., pp. 436-460.

Fageria, N.K., Baligar, V.C. and Jones, C.A. 2011. Growth and mineral nutrition of field crops, CRC Press, Boca Raton, New York, U.S.A., pp. 195-218.

Goh, K.J. and Chew, P.S. 2000. A Lecture note on agronomic requirements and management of oil palm for high yields in Malaysia. In Goh, K.J. (ed) Seminar on Managing Oil Palm For High Yields: Agronomic Principles, July 11th 2000, Lumut, Perak, Malaysian Society of Soil Science, Kuala Lumpur, 39-73.

Goh, K.J. and Chew, P.S. 1997. Interpretations of analytical data from soil survey reports for manuring recommendations: some pointers. Annual Journal/Report, Royal Johore Planters' Association, 25-30.

Goh, K.J. and Chew, P.S. 1995. Managing soils for plantation tree crops 1: General soil management. In Course on Soil Survey and Managing Tropical Soils. MSSS and

PASS, Kuala Lumpur, Malaysia, 228-245.

Huber, D.M. 1980. The role of mineral nutrition in defense. In Horsfall, J.G., Cowling E.B. (eds). Plant disease, an advanced treatise. How plants defend themselves. Academic, New York, U.S.A., pp. 381-406.

Isaaks, E.H. And Srivastava, R.M. 1989. An introduction to applied geostatistics, Oxford University Press, New York, U.S.A., pp. 561.

Johnson, D.W., Henderson, G.S. and Todd, D.E. 1999. Changes in nutrient distribution in forests and soils of Walker Branch Watershed, Tennessee, over an eleven-year period. Biogeochemistry. 5, 275–293.

Kee K.K., Goh K.J. and Chew P.S. 1995. Effects of NK fertilizer on soil pH and exchangeable K status on acid soils in an oil palm ecosystem in Malaysia. In Date, R.A., Grundon, N.J., Rayment, G.E. and Probert, M.E. (eds). Plant-Soil Interactions at Low pH: Principles and Management. Developments in Plant and Soil Sciences Vol. 64, Kluwer Academic Publisher, The Netherlands, 809-815. Presented at 3rd International Symposium Plant Soil Interactions at Low pH, Brisbane, Australia, 1993.

Malaysian Palm Oil Board (MPOB). 2013. Oil palm planted area. Economic and Industry Development Division, Malaysian Palm Oil Board. Available from: http://bepi.mpob.gov.my/images/area/2013/Area_summary.pdf (April 20, 2014).

Marschner, H. 1995. Mineral Nutrition of Higher Plants, 2nd ed. Academic Press, New York, U.S.A., pp. 436–460.

Mutert, T., Fairhurst, H. and von Uexküll, H.R. 1999. Agronomic management of oil palms on deep peat. Better Crops International. 13, 22-27.

Myers, J.C. 1997. Geostatistical error management quantifying uncertainty for environmental sampling and mapping, Thomson Publishing, New York, U.S.A.

Ng, H.C.P., Gan, H.H. and Goh, K.J. 2011. Soil nutrient changes in ultisols under oil palm in Johor, Malaysia. Journal of Oil Palm and the Environment. 2, 93-104.

Parkin, T.B. 1993. Spatial variability of microbial processes in soil: a review. Journal of Environment Quality. 22, 409-417.

Pimentel-Gomes, F. And Garcia, C.H. 2002. Statistics applied to agronomic and forestry experiments. In Pimentel-Gomes, F. (ed.). Exposure to examples and guidelines for use by applications, 1st edition. Fealq-Esalq, Piracicaba, Brazil, pp. 309.

Prasad, R. and Power, J.F. 1997. Soil fertility management for sustainable agriculture. Lewis Publishers, New York, U.S.A., pp. 356.

Rengel Z., 2002. Regulation of microbial processes by soil pH. In Handbook of plant growth. CRC Press, New York, U.S.A.

Nur Sabrina, N. A., Sariah, M. and Zaharah, A. 2012. Suppression of basal stem rot disease progress in oil palm (*Elaeis guineensis*) after copper and calcium supplementation. Pertanika Journal Tropical Agricultural Science. 35, 13-24.

Singh, G. 1991. *Ganoderma*- The scourge of oil palm in coastal areas. The Planter. 67, 421-440.

Sun, B., Zhou, S. and Zhao, Q. 2003. Evaluation of spatial and temporal changes of soil quality based on geostatistical analysis in the hill region of subtropical Chinese. Geoderma.115, 85-99.

Unites States Department of Agriculture (USDA). 2014. Oilseeds: World Markets and Trades. Foreign Agricultural Service, Washington, U.S.A. pp. 34.

Usherwood, N.R. 1980. The effects of potassium on plant disease. In Potassium for Agriculture: A Situation Analysis. Potash and Phosphate Institute editor. Potash and Phosphate Institute, Atlanta, pp. 151-164.

von Uexküll, H. R. and Fairhurst, T. H. 1991. Fertilizing for high yield and quality: The oil palm.12th edition. International Potash Institute, Basel, Switzerland.

Webster, R. 1985. Quantitative spatial analysis of soil in field. Advance in Soil Science. 3, 1-70.

Williats, W.G.T., Mc Cartney, L., Mackey, W. and Knox, J.P. 2001. Pectin, cell biology and prospects for functional analysis. Plant Molecular Biology. 47, 9-27.

Woltz, S.S., Engelhar, A.W. and Mayer, R.S. 1992. *Fusarium* wilts on chrysanthemum effects of nitrogen source and lime on disease development. Phytopathology. 63, 155-157.

Ycock, R. 1966. Stem rot and other diseases caused by *Sclerotium rolfsii*. N.C. Agricultural Experiment Station and Extension Technical Bulletin. 174, pp. 202.

Yost, R.S., Uehara, G. and Fox, R.L. 1982. Geostatistical analysis of soil chemical properties of large land areas: Semivariograms. Soil Science American Journal. 46, 1028-1032.

Zhou, H.Z., Gong, Z.T. and Lamp, J. 1996. Study on soil spatial variability. Acta Pedology Sinica. 33, 232-241.