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PREDICTING THE VARIABILITY OF COPPER AND ZINC IN LEAF AND SOIL OF OIL PALM PLANTED ON A 12 HA LAND USING GEOSPATIAL INFORMATION SYSTEM TECHNOLOGY

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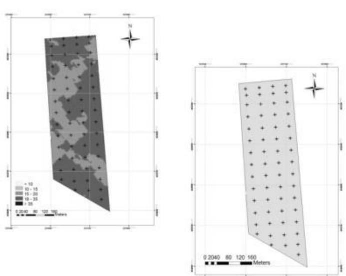
Graphical abstract



Abstract

Oil palm (*Elaeis guineensis*) is an important economic tree crops in the tropic. However, more than 95 % of oil palms grown in Southeast Asia are on acid, low fertility and highly weathered soils. Optimum value of micronutrients in the soil was required to enhance the efficiency of use of macro-nutrients. Hence, to observe and predict the fertility status of the oil palm plantation area, a 12 hectare study site was used and a total of 60 geo-referenced soil and leaf samples were collected for determinations of pH and selected micronutrients of Cu and Zn content. The data were explored and mapped using geostatistic and Geographic Information System (GIS). The study area had acidic type of soil with pH ranged from 3.25-5.85. The analysis showed that almost 78% of the study area had high content of Cu in soil, while another 22% of area was low to moderate in Cu. However, Cu content in leaf were categorized as insufficient as 100% of the area was observed to have Cu less than 3 ppm. About 80% of the study area showed a low to moderate content of Zn in soil, while another 20% of area showed a high content of Zn. Zinc content in leaf ranged from optimum to high categories. However, this value did not reach the excess level of Zn (50 ppm). These results suggest that, this plantation area need a site specific management approach in order to increase its crop productivity in regards to nutrient management. As a preliminary recommendation, a zone management practice would be applied in future as it is beneficial in term of protecting the environment from excessive fertilizer.

Keywords: Spatial variability, geostatistic, copper, zinc, precision agriculture

1.0 INTRODUCTION

Precision agriculture is a system of management that aims to create a sustainable agriculture and to reduce environmental degradation, which often associated with economic activity [1]. It integrates the crop requirements with the variability of land characteristics by an agronomic practice with considerations of space and time factors [2]. It has been received significant attention due to it's beneficial in reducing environmental risk, increasing crop productions and raises the input efficiency through soil management system [3]. One of the best approaches in applying the concept of a precision agriculture is through a site specific management system using geostatitstical analysis and spatial variability map. Geostatistical analysis offer quantitative information about spatial variability, which is the theory of requirement for site specific management. It had been used previously in quantifying the chemical [4, 5], physical [6] and morphological of soil properties in an area. It consists of variography that explains the spatial variance of the data and kriging, which later used to model and mapped the variance and estimates the value of unsampled locations.

The soil is a non-uniform complex, which its nutrients properties is controlled by the natural and human factors. This includes the parent materials, climate, fertilization and weathering. As a consequence, variability conditions of soil were exhibited at the macro- and micro-scales [7]. Site specific management of nutrients provide the farmer the possible amounts of exact nutrient required at each given site in a field. In other words, site specific management practise acts on targeting areas by assuming that the area is heterogeneous. Unlike the homogenous managements of crops, which assume that all the nutrients were the same in each site. This type of practices result in less than optimum yield and nutrient deficiency, as excessive or insufficient fertilizer may acts at different efficiency level.

Oil palm has becoming one of the most important crops in Malaysia. Its cultivation occupies approximately 14% or 4.85 million hectares of the land area in Malaysia. Its contribute 47.9% of the world palm oil production with exports revenue earnings from oil palm products of more than RM60 billion in the year of 2010 [8,9]. The need for site specific practices in oil palm plantation is generally driven by stagnant productivity but highly input cost over the years, since it was planted. Fertilization is often reported as one of the biggest cost component in operating budget. Thus, the site specific management concept seems as an attractive solution to counter this existing problem. Currently, there is limited information about spatial variability of Copper (Cu) and Zinc (Zn) in oil palm plantation area. Over fertilizing with Cu and Zn for instance can lead to ground water pollution and caused detrimental effects and deficiency of those elements also could leads to reducing of its oil palm production. Hence, the objectives of this study were: i) to determine the spatial dependency of measured Cu and Zn and ii) to quantify the spatial variability of Cu and Zn over a large area by using geostatiscal and GIS techniques.

2.0 MATERIALS AND METHODS

2.1 Soil and Leaf Sampling

The study was conducted in a commercial oil palm plantation located at Seberang Perak, Perak (4°06'41.50"N, 100°53'05.71"E). The oil palm plantation area were planted in year of 2006 with planting density of 160 palm/ha. The study block sized 12 hectare (ha) of area and is mainly composed of local alluvium soil of 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 was 1500 mm with mean annual temperature of 29.8°C.

Soil and leaf samples were obtained systematically by grid sampling techniques consists of 60 georeference points in the study block (Figure 1) Sampling points were spaced approximately 36 m in the X and Y direction. Three composites of soil 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 analyses.

Extractable Cu and Zn were determined by Mehlich I method [10], which is more suitable for acid soils. A total of 5 g soil were shaken for 15 minutes with 25 ml extract solution containing 0.05N HCl and 0.025N H_2SO_4. These filtered solutions were then measured with atomic absorption spectrophotometer (AAS) (Perkin Elmer 400, USA). Evaluation of Cu and Zn content of this study was made on threshold value suggested for soil [11, 12]. Soil pH was determined using the glass electrode pH meter (Metler Toledo FE20, Switzerland) using soil: water ratio of 1: 2.5.

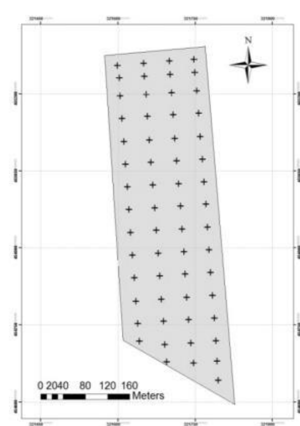


Figure 1 Sampling points of study area

Leaf samples were collected from the 17th fronds, which is a representative of leaf tissue samples. This was taken out during the morning hours (0700 to 1200 hours). The leaves were selected from both sides of the central leaflets of frond for about 20 leaves. It 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 tes, while the ends were discarded. Leaflets were oven dried at 60 to 70°C for 2 days. Then the samples were ground and passed through 200 µm 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 using AAS (Perkin Elmer 400, USA). The spatial distribution of Cu and Zn were classified based on treshold value suggested for oil palm plantations [13].

2.2 Geostatistical Data Analysis

The spatial contuinity of Cu and Zn was performed in two stages; 1) determining the spatial structure of the nutrients using variography structure and 2) interpolation of the nutreints within the study block using point kriging methods. Variograms measures and model the spatial dependence of variables, such as nutrients by using a semivariance [14]. They were calculated for each nutrient as follows (15].

$$\gamma(h)=\frac{1}{2N_h}\sum_{i=1}^{N_h}\left[\left(Z_i-Z_{(i+h)}\right)^2\right]$$

h is the separation distance between location Xi or Xi+h, or zi or zi +h are the measured values for regionalized variable at location xi or Xi+h and (h) is the number of pairs at any separation distance h.

A semi-variogram, models the continuity of the spatial variable to a spatial structure. It is described by several parameters such as sill, nugget, and range. Models were selected based on the fitting of the data, which more favourable 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[16] to guide the selection process includes, (i) Semi-variogram 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. Spatial dependence of each element was described using nugget to sill ration[17], which was interpreted as in Table 1.

Table 1 Definition of spatial dependence

Nugget:Sill <25%	Strong spatial dependence
25< Nugget:Sill >75%	Moderate spatial dependence
Nugget:Sill >75%	Weak spatial dependence

2.3 Mapping of Soil and Leaf Nutrient Properties

Spatial variability map of soil and leaf nutrients were generated using ordinary kriging techniques in Geospatial Informtaion System technology (GIS) of ArcGIS 10.1 based on the obtained semivariogram parameters from the variograms value.
Initially, required values of variogram, such as nugget, partial sill, and range were derived using the geostatistical analysis of GS+7.0. This technique was used to develop a map of soil and leaf fertility status and to map nutrient and amendment requirements at regional level. The zone of the nutrients was classified based on the value of soil and leaf fertility evaluation suggested by the mentioned threshold value above.

3.0 RESULTS AND DISCUSSION

3.1 Descriptive Statistical Analysis

Coefficient of variance (CV) described the behavior of the attributes within the study area. Higher value of CV reflects higher variability occurrence and vice versa [18]. Soil was categorized into acidic type with pH ranged from 3.25 to 5.85 (Table 2). The oil palm was able to tolerate acidity type of soil and can grow well under broad scale of soil pH ranged from 4.0 to 5.5 [19]. The Coefficient of variance (CV) of pH were less than 10%, indicated that pH had the lowest variation throughout the study area. Low pH variation indicates that the pH within the study areas were homogenous. Other researchers had documented a lower variance of soil pH compared to other soil chemical properties [20, 21, 22]. 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 [23].

Table 2 Univariate statistics of Cu and Zn contents

		Mean	Range	CV%
pH	**Soil**	4.41±0.39	3.25-5.85	8.84
Cu (ppm)	**Soil**	1.47±0.74	0.13-3.25	50.34
	Leaf	1.78±0.73	0.70-3.25	41.01
Zn (ppm)	**Soil**	2.24±1.41	0.24-6.93	63.07
	Leaf	20.61±7.38	9.44-42.56	35.80

Nevertheless, CV for Cu and Zn content in both soil and leaf were very high with value more than 30%. The larger variance found could be linked to heterogeneity of the land use management and fertilization scheme. Any changed of land use pattern, such as harvesting, drainage, and burning will affects the chemical properties of the soil and its impact could be different for several chemical properties [23]. It is well established that CV of soil chemical properties are often more than 30%, which shows that it has a high variability [15]. Such variability has been shown to occur spatially and temporally [24].

3.2 Geostatistical Data Analysis

Semivariogram of Cu and Zn in soil and leaf were constructed based on active lag of 320m. The geostatistical summary was presented in Table 3 and the model structure was depicted in Figure 2. All of the variables showed a definable spatial structure that was described by a Gaussian model, except for Zn in leaf, which was described by Exponential model. A positive with low nugget value obtained in all of the attribute suggested only small error had occurred during the sampling, analytical and estimation process. The Cu content in leaf showed a moderate spatial dependence with 46.76% of its total variation attributed to spatial variability, while others properties were subjected to strong spatial dependence. This physically means that more than 75% of proportion of the total variation in leaf Zn and Cu and soil Cu were explainable, while the remaining variation attributable to random sources. The strong spatial dependency of a soil property can be attributed to intrinsic factors (natural factors such as parent material), while the moderate spatial dependence obtained in leaf Cu could be caused by intrinsic (leaf-forming processes) and extrinsic factors (fertilization, cultivation and soil management practices) [24].

All of the soil and leaf properties had a short effective range (ER) i.e., <70 m. The significance of ER is that, any sampling points separated at distances greater than this value did not exhibit any correlations anymore. Sampling designs were aimed to describe spatial structure and usually employ separation distance s that is lesser than the ER. Based on this, sampling of soil for Cu and Zn content were appropriate, while sampling of leaf for Zn should be closer than others. However, in overall it can be suggested that the sample spacing should be closer in future.

Table 3 Summary of the spatial structure of Cu and Zn

Element	Model	Nugget (C_o)	Sill ($C+C_o$)	ER (A_o) (meter)	Nugget:Sill ($C_o/(C+C_o)$) (%)	R^2	RSS
				Copper			
Soil	Gaussian	0.031	0.510	46.00	6.07	0.97	2.28×10^{-3}
Leaf	Gaussian	0.032	0.074	48.60	43.24	0.87	1.45×10^{-4}
				Zinc			
Soil	Gaussian	0.0001	0.257	43.20	0.04	0.87	2.08×10^{-3}
Leaf	Exponential	0.012	0.073	17.80	16.43	0.63	1.45×10^{-4}

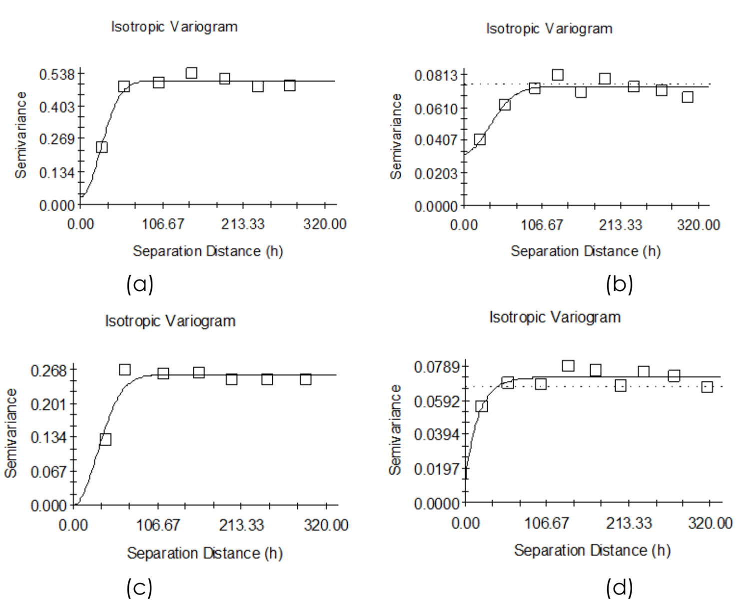


Figure 2 Spatial structure of (a) Cu in soil (b) Cu in leaf (c) Zn in soil (d) Zn in leaf

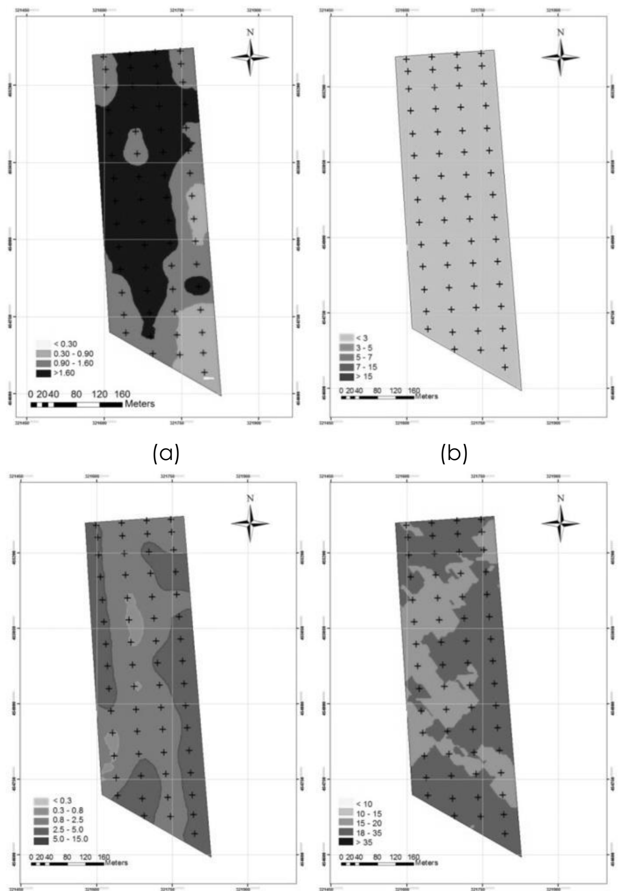
3.3 Spatial Variability Mapping

Distributions of Cu and Zn content in soil and leaf were illustrated by a contour map with gradiation scheme (Figure 3). The centre part of the block had a very high content of Cu in the soil with area covered around 77.78%. Copper content at the outer part of the block ranged from low to moderate level with area covered about 22.22%. However, Cu content in leaf were found to be insufficient as 100% of the area had Cu content less than 3 ppm .

Variability of Cu in soil occurs due to the addition of fertilizer, crop residue, farmyard manures and also weathering of soil minerals. These variables affect the Cu content in soil to decrease or increase spatially. Nevertheless, deficient Cu level found in leaf throughout the blocks could be affected by high content of N and P in soil. At high N rates, it suppresses the availability of Cu in crop plants [25]. This factor could be linked to this study, where high N content was found throughout the blocks. In this study N were found more than 0.25% in the whole study area. Optimum total N content in soil should be about 0.15% This evidence might caused the content of available Cu for the plants requirement was restricted. High application of N rates applied to the matured oil palm in North Sumatra, clearly depressed the content of both Cu and Zn levels in leaf. Similar study also found out Cu deficient in soil was positively related to high application of N and P [26].

Low to moderate categories of Zn were aggregated at the central block stretching from the north to southern part of the block with area covered around 80%. Higher level of Zn was found at the outer part of the block ranged from 2.50 to 5.00 ppm. Zinc content in leaf ranged from optimum to high categories within the study block. However, this value did not reach the excess level of Zn (50 ppm). It was noted that, the categories beyond the optimum Zn level covered the study block around 8.03 ha. Variability of Zn in an area depends mainly on the factors of fertilizer, crops residue and soil minerals. This caused high and low content of Zn in this block. Its depletions in soil are caused by erosions and uptake by plant. Different land management caused the Zn content to vary spatially within blocks. Among micronutrient deficiency, Zn deficiency is also common which could be due to intensive cropping and topsoil erosion [27].

It was observed that there was a spatial variability among Cu and Zn contents in both soil and leaf samples within the 12 ha study area. This could be due to the difference between various soil management practices by the farmers that also results in variability of Cu and Zn content in leaf. The map of Cu and Zn in soil and leaf had clearly explained information about the spatial distribution of its content throughout the study area. Appropriate fertilization is recommended to increase the efficiency of the nutrients, which results in increasing yield and also to reduce fertilizer cost. Application of site specific management programme might be introduce to apply the fertilizing scheme in long term period. However, the soil properties such as soil texture, ph, chemical values, should also be considered in managing the nutrients availability.



(a) (b)

(c) (d)

Figure 3 Spatial variability of a) Cu in soil (b) Cu in leaf (c) Zn in soil (d) Zn in leaf

4.0 CONCLUSION

This study reveals major variability of Cu and Zn in soil and leaf nutrient status in 12 ha of area in oil palm plantation situated in Seberang Perak. Majority of the variables showed strong spatial dependency with short ER, which indicates the need of using closer sample spacing in future to account spatial correlations and higher variability occurred at the sampling area. Spatial maps showed almost 78% of the study area had a high content of Cu in soil, while about 80% of the study area showed a low to moderate content of Zn. Leaf Zn ranged from optimum and/or higher categories, while Cu content were found to be deficient with value found less than 3 ppm within the study block. These combined data suggest the technology of GIS were reliable and efficient in monitoring and managing fertilization accross large plantation areas.

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