EVALUATION OF SPATIAL VARIABILITY OF SOIL IN AN OIL PALM PLANTATION

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Abstract
The study was carried out at Dusun Durian Estate, Golden Hope Plantations Berhad, Banting, Selangor, Malaysia, in a 50 ha plot which represents a coastal oil palm plantation. The general objective of this study was to obtain accurate and timely information about the spatial distribution and status of of nutrients in the soil using GIS and remote sensing technology. Collection of soil data were conducted by systematic sampling, and an Omni Star Differential GPS was used to precisely determine sample site location. Geostatistics (GS+) software and classical statistics were used for data analysis. SPOT image of K-J 299-344 acquired on March 2000. Descriptive statistical analysis classed the status of total N as low, whereas available P and exchangeable K varied from moderate to high. Soil exchangeable Ca and Mg ranged from low to moderate. Soil variability of available P, exchangeable K, Ca and Mg status were classified as high, but moderate for total N. Semivariance analysis showed that the total N, available P and exchangeable K in the soil have a moderate spatial dependence, while there was a strong spatial dependence for exchangeable Ca and Mg with available lag distance of 52 m to 117 m. SPOT image analysis could not be used to predict nutrient content in the soil and leaf tissue.

Additional Keywords: Spatial variability, Geostatistical analysis, soil nutrient, SPOT

Introduction
Spatial variability of soil properties has been one of the major objectives in investigations related to agricultural and environmental sciences. Webster (1985) reported that Geostatistics is a method to analyze spatial variability of soil properties. It provides the basis for describing spatial variation in soil quantitatively, for estimating soil properties and mapping them, and for planning rational sampling schemes that makes the best use of manpower. The objective of this paper is to evaluate the spatial variability of major nutrients (N, P and K) in coastal oil palm plantations as a scientific basis for rational soil sampling as well as for site-specific soil management for oil palm plantation.

Materials and Methods
Site Description and Data Collection
The study was carried out in March 2000 on a coastal Fluvaquentic Endoaquept soils in Golden Hope Plantations Bhd. Banting, Selangor, Malaysia, located within coordinates 311144 to 312062 m north and 385825 to 386305 m east. The total annual rainfall is about 1951 mm per year, with the minimum rainfall of about 75 mm/month occurring in February, and maximum rainfall of 276 mm/month in November.

Sample sites were selected systematically within distance of about 54 x 30 m in the whole study area. An Omni Star Differential GPS was used to locate the position of every sample point. A total of 648 soil samples were taken at two depths (0-15 cm and 15-30 cm) from the frond-pile and at inter-rows, respectively.

Soil, Statistical and Geostatistical Analysis
Soil samples were air-dried and passed through a 2 mm sieve before analysis. Total organic carbon (OC) was measured using the Walkley and Black method; and total N was determined by the Kjeldahl method. The molybdenum-blue method was carried out to determine the available P in the soil. Exchangeable K in the soil was determined by the leaching method using ammonium acetate and potassium chloride.

Descriptive statistics of soil nutrient status and relationship of the variables was conducted using SPSS statistical software version 10.0 and SigmaStat version 2.0. ANOVA and T-test were used to ascertain the differences in variations of a variable between top and sub layers. CV values from 0 to 15% was classed as little or low variability, from 16 to 35% was moderate variability and greater than 35% was great or high variability (Wilding, 1985).

Geostatistical software, GS^+ version 3.1 for Windows was used to analyze semivariograms and kriged map of the variables. The spatial dependence classification was used based on the ratio of nugget and sill. A map of each variable was computed subsequently using point kriging, by taking account of the data within the range.

MapInfo and Digital Image Analysis
MapInfo software version 5.0 was used for spatial analysis of kriged map of each variable. The image processing of SPOT data was conducted using PCI software.

Results and Discussion
Spatial Variability of Total N, Available P and Exchangeable K in Soil
Descriptive Statistics
The variability of total N in the soil at top-layer (N1) and sub-layer (N2) ranged from 0.10 to 0.55% and 0.04 to 0.5%, respectively. The mean value of total N at top and sub-layers were classed as low. Coefficient of variation (CV) of total N at sub-layer is higher (CV= 34%) than total N at top-layer (31%), meanwhile all the CV of total N in the soil could be classified as moderate variability. Total N at top-layer was about one and half times higher than in sub-layer. Statistical analysis indicated that the total N at top-layer was significantly higher than the sub-layer ($P \leq 0.05$). This is probably due to the higher organic residues deposited on the soil surface than the sub surface soil. Further analysis indicated that total organic carbon (OC) at top-layer was significantly different ($P \leq 0.01$) compared with the sub-layer. Total N in top and sub-layers correlated significantly ($P \leq 0.05$) with the total OC and exchangeable K in the soil.

Available P at top and sub-layers varied from low to very high. Based on the CV values, soil variability of available P for both of top and sub-layers was considered as high. The variability at sub-layer (CV = 72 %) was higher than available P at top-layer (CV = 69%). Statistical analysis indicated that there was a significant difference between available P at top-layer and sub-layer ($P \leq 0.05$). This condition is probably due to difference of soil pH and total organic carbon between the layers. Statistical analysis revealed a high significant difference ($P \leq 0.01$) of soil pH and total OC at the top and sub-layers of the soil. The available P in the soil was highly correlated ($P \leq 0.01$) with soil pH.

The exchangeable K at top-layer was classified as moderate to very high, whereas that of the sub-layer ranges from low to very high. Soil nutrient variability of exchangeable K at top-layer was higher than K at sub-layer, but both layers were categorized as high. Statistical analysis indicated no significant difference ($P \leq 0.05$) between exchangeable K at top and sub-layers. Exchangeable K at both layers was highly correlated ($P \leq 0.01$) with the total N, and total OC in the soil. Cations held in this manner are easily displaced or exchanged when the soil is brought into contact with neutral salt solution.

Semivariance Analysis
The semivariance analysis for total N in the soil was characterized by a semivariogram. The best-fit model for total N in the soil was spherical. The nugget values (Co) were low (0.0278-0.0245), indicating the small error of the estimation processes. The sources of errors in estimation process may be due to many factors such as sampling intensity, positioning chemical analysis, data recording and soil properties. The low residual sums of square (RSS) values (4.0×10^{-5} to 1.3×10^{-4}) indicated the best models that fit the variogram data analysis. The nugget ratio results showed that both of total N in the soil could be classified into moderate spatial dependence within the lag distance of about 58 m and 52 m for soil N at top-layer and sub-layer, respectively. This result demonstrates that future sampling of soil N should be within 52 to 58 m. Therefore, soil sample for total N analysis should be represented by at least four samples ha^{-1}. Otherwise, any pair of nutrient values by a lag distance greater than that range would be spatially independent.

The fitted model for available P in the soil was an exponential. The low of RSS value (3.8×10^{-3} to 1.8×10^{-2}) indicated a good model fit. Available P at top-layer was classified as moderate spatial dependence within the lag distance of 117 m, while that of sub-layer as strong spatial dependence within a lag distance of 141 m. This result implies that the best distance for available P analysis in soil is about 117 m to 141 m. Otherwise, any pair of nutrient values with a lag distance greater than 141 m is spatially independent.

The low RSS (0.0002 to 0.0049) and nugget ratio values (0.28 to 0.31) indicated the model chosen fits the variogram data well and has a moderate spatial dependence within the lag distance of about 66 m for the top layer and 45 m at sub layer. Low nugget value (Co) in this study (0.161 for top-layer and 0.062 for sub-layer) indicated a small error of the estimation process. The errors in the estimation process could be caused by many factors such as sampling intensity, positioning, chemical analysis, data recording and soil properties. This result suggests that future soil sampling for exchangeable K analysis should be within 45 to 66 m.

Kriged Maps

Kriged map analysis indicated that total N at sub-layer varied from 0.04 to 0.05% and was classed as low. Meanwhile, total N at top-layer could be classed as low, which represents 93.3% of the study area and the remaining 6.7% as moderate. This result indicated that the total N of the study area can be generally classed as low, although there are some small areas in the top-layer that could be classified as moderate. During the rainy season, the study area had a high water table. The excess water flow out into drainage canals and could probably carry away some soil N. The inorganic N was lost as solute in the water, whereas organic N was lost as humus or organic mater. Leaching can also cause loss of inorganic N, as it goes to the deeper level in the soil profile following the water flow. Leaching can be accelerated by preferential flow of water through armyworm or root channels, natural fissures and cracks in soil.

Soil available P at the top-layer (PI) was classified as moderate, which represents 88.4% of the total area. The remaining could be classified into low (0.9 %), high (10.1%) and very high (0.6%), Meanwhile, soil available P at the sub-layer (P2), could be classified low (21.1%), moderate (73.7%), high (3.5%) and very high (1.7%).

The soil exchangeable K in the study area varied from moderate to very high for top-layer and varied from low to very high for sub-layer. The soil exchangeable K at top-layer (K1) represents 62.9% of the total area that could be classified as moderate, and the remaining 35.0% and 2.1% classified as high and very high, respectively. Soil exchangeable K at the sub-layer (K2) could be classified into low (4.2%), moderate (79.7%), high (15.6%) and very high (0.5 %).

SPOT Image Analysis

The digital number (DN) of all the palm sample sites of the SPOT image analysis using PCI software varies from a minimum value of 37 in the B band to a maximum of 150 in the R band. It was found that the G channel had a significant correlation ($P \leq 0.05$) with the selected nutrient content in leaf tissue of N ($R = 0.146$) and Mg ($R = 0.136$). The B channel also had a significant correlation with the concentration of K in leaf tissue ($R = 0.145$). The strength of the relationship for both B and G channels with the nutrients that DN analysis of SPOT image cannot be used to predict nutrient content in the leaf tissue. The probable reason is that the oil palm leaves did not completely cover the soil surface. Therefore, the reflectance value that received of the image was not fully represented of the palm leaves reflections, but also influenced by the soil.

Conclusions

Total soil N in the study area can be classified into low to moderate level, whereas, available P and exchangeable K varied from low to very high levels. Total N had a strong relationship with soil organic C, while available P was highly correlated with soil pH. Geostatistical analysis showed that both of total N at top and sub-layers could be classified as moderate spatial dependence with the lag distance of about 58 m for top-layer and 52 m for sub-layer. Soil available P at top-layer was classified as moderate, while strong spatial dependence within the lag distance of about 117 m for top-layer and 141 m for sub layer. Meanwhile, exchangeable K in soil both at top and sub-layers had a moderate spatial dependence, with the lag distance of about 66 m and 45 m for top and sub-layers, respectively. SPOT image analysis indicated that there was no strong relationship between DN of all the channels (R, G and B) and all the nutrients concentration (N, P, K Ca and Mg) in leaf tissue. Therefore, SPOT analysis using DN cannot be utilized to predict the nutrient content in leaf tissue.

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