RESEARCH ARTICLE

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Spatial Variability of Total Nitrogen, and Available Phosphorus of Large Rice Field in Sawah Sempadan Malaysia

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ABSTRACT Accurate information on the spatial variability of soil chemical properties is very important in developing site-specific management for large rice field. Therefore, sampling procedure for soil nutrients status validated for developing variable rate of application of nutrients for rice is essential. Variability of total nitrogen(N), and available phosphorus(P) was examined on 2300 ha rice field. The soil samples (n=240) were taken from 120 points; two points in each plot were taken at two depths: top-soil (0-20 cm) and sub-soil (20-30 cm). Collection of the soil samples has been done in order to cover all types of the soil series dominant in the study area. Differential global positioning system (DGPS) was used to locate the sample position, and variability of soil chemical properties was analysed by geostatistical techniques. Total N, and available P varied greatly for both depths as indicated by variogram analysis. The range of total N varied between 0.434 and 0.475 km for top- and sub-soil depth, respectively, and available P between 0.597 and 0.610 km for top- and sub-soil depth, respectively. The kriging maps showed the spatial variation for soil chemical properties measured. The results suggest that soil chemical properties measured may be useful in the field management zones that could maximize application benefits.

KEYWORDS: geostatistics, spatial variability, semivariogram, point kriging, soil fertility.

INTRODUCTION

Currently, new and better technologies facilitate the introduction of site-specific management in agriculture. Site-specific management creates high expectations: higher financial returns, increased product quality, and decreased environmental risks. Worldwide, interest among agro-business, traders, and researchers is increasing because of the potential benefits of precision agriculture.

Soil properties are usually studied by taking samples on some grid or other pattern[1,2] with the assumption that properties measured at a point also represent the unsampled neighborhood. The extent to which this assumption is valid depends on the degree of spatial dependence that exists among the samples. Understanding the spatial variability of field soil is important for crop production.[3,4] Considerable effort has been made to evaluate the variability of soils.[5] The variability of soil properties within the field is often described by a classical method, which assumes that the variation is randomly distributed within mapping units. Soil variability is the outcome of many processes acting and interacting across a continuum of spatial and temporal scales and is inherently scale dependent.[6]

Many studies have been conducted to investigate the variability within the field in the large area.[7] studied the correlation between soil chemical properties of Loess-derived soils sampled as far apart as 45 km in western Kansas. Campbell[8] used geostatistical methods to compute and display semivariogram for soil texture and soil pH of Loess and glacial-till-derived soils. These results suggested that application of concepts on spatial dependence could help in understanding and deal more effectively with variability in soil characteristics. The influence of distance or spatial location of a soil sample can be used as an element of potentially useful information that was seldom considered.

Different rate of nutrient application is possible only if experts can give correct site-specific recommendations. Therefore, precise information about nutrient status of the soil is required.[9-11] The translation of the field information into site-specific recommendation could be done when the spatial variation in nutrient status across a field is quantified.

The objectives of this study was to determine the structure of spatial dependence of soil chemical properties selected over relatively long distances and to examine and interpret semivariogram of soil chemical properties selected.

Materials and Methods

The study was conducted at the Sawah Sempadan rice plantation area. Located on a flat coastal plain in Northwest Selangor Agriculture Development (PBLS), it is in the districts of Kuala Selangor, Sabak Bernam at latitude $3^0\,35^{''}$ and longitude $101^0\,05^{''}$. The area of study is 2300 ha and gives an overview of the boundary of the study area is given in Figure 1. Five major soil series, Jawa, Teluk, Karang, Sempadan and Sedu dominate the soil.

Soil Collection and Laboratory Analysis

Sixty plots were selected for the study as shown in Figure 1 with two locations from each plot; the distance between two locations within the plot is 50 m, at two depths (0-20 cm, and 20-30 cm). The soil samples were collected before planting on March 2001. Sampling points were taken using a DGPS unit to provide precise sample location, with an error ± 1 m. At each point the values were converted to the x and y coordinates. A composite soil sample was taken for each location using soil auger (j=2.5 cm) according to procedure published by.[12] The samples were packed into plastic bags. The samples were then airdried and ground to pass through a 2 mm sieve for further analysis. The following soil properties were measured: total nitrogen(N) by sulfuric-salicylic acid digestion method[13] and available phosphorus(P) were determined by NH_4F-HCl extraction method.[14]

Geostatistical Analysis

A geostatistical analysis of the data was performed to determine the spatial structure of total N and available P at the two depths separately within the study plot

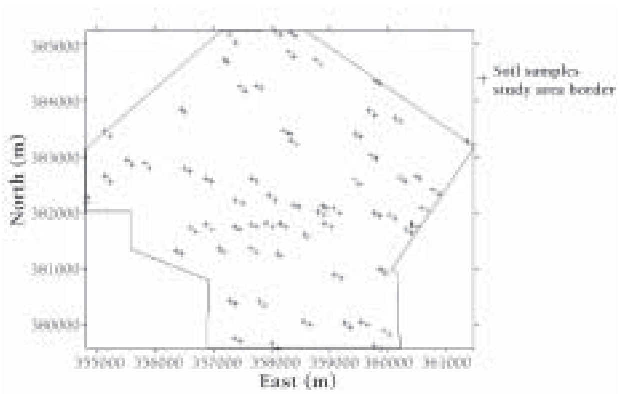

Fig 1. Plots of soil samples sites using DGPS.

using Geostatistical software (GS+, Gamma Design Software, St Plainwell, MI, version 5.0.3 Beta).[15] The GS+ has a number of models that can be fitted to estimate semivariogram by using non-linear square procedure. The spherical and linear models were used in this study. The spherical model was shown below:

$$\gamma(h) = C_0 + C\left\{\frac{3|h|}{2r} - \frac{1}{2}\left(\frac{|h|}{|r|}\right)^3\right\} \text{for } 0 < |h| \le r$$

$$\gamma(h) = C_0 + C \quad \text{for} \qquad (1)$$

$$\gamma(0) = 0,$$

Where, = is the semivariance,

C_0 = is the nugget variance which is defined as the semivariance at h =0, which h is the lag distance.

($C_0 + C$) = is the sill which the maximum semivariance was defined as the sill, and

r = is the range of spatial correlation (Vauclin *et al*, 1983).

The nugget to sill ratio was used to qualitatively define spatial dependence values. The values less than 25 % have strong spatial dependence, the values between 25 % and 75 % are considered as moderate spatial dependence, and the values greater than 75 % have weak spatial dependence. The selection of the best model was based on more favorable weighted residual mean squares, and visual fit to the data at short lags. The contour maps were developed using the Surfer software (Golden Software, Inc.; version 7, 1999).[17]

The kriged or spatial maps for total N and available P were constructed by using point kriging method[18-19] to estimate the values at unsampled locations and then clustering them in 3-5 ranges with equal contours intervals. The ranges for soil nutrients were five classes according to DOA.[20]

Results and Discussion

Variations of Soil Properties

The measured soil attributes varied considerably. Summary of the statistics of the soil properties measured is given in Table 1. By comparing the median with the average values, all parameters showed a normal distribution. The coefficient of variation (CV) for the total nitrogen(N) was between 21 and 26 % at the top- and sub-soil depths, respec-tively. The variation in the available phosphorus (P) was is varied between 44 and 55 % at the top- and sub-soil depths, respectively. This variation could be due to different a mounts of fertilizers. The data in Table 1 showed a greater variation in the values of available P compared with those of the total

N at both depths.

Geostatistical analysis indicated different spatial dependence levels for the measured parameters. The main characteristics for the semivariogram are given in Table 2, for the total N and the available P at both top- and sub-soil depths. The intercept, which is the estimate of at = 0, provides an indication of short distance variation. The nugget variance varied between the two depths, with the values of 0.001 and 0.005 % for the total N, and 69 and 173 (mg/kg soil) for the available P, at the top- and sub-soil depths, respectively. The range of the semivariogram is the distance (h) at which γ attains the maximum value (sill). Often the sill approximately equals to the sample variance.[21] The values of the sill variance for all nutrients studied varied between 0.008 and 0.009 % for the total N, and 491 and 316 (mg/kg soil) for the available P at the top- and sub-soil depths, respectively.

The range is expressed as distance and can be interpreted as the diameter of the zone of influence, this value represents the average maximum distance over which a soil property of two samples is related. At a distance less than the range, the measured properties of two samples become more alike with decreasing distance between them. Thus, the range provides an estimate area of similarity. The zone of influence for the total N and the available P is shown in Table 2, which is represented by the range that varied between 0.460 and 4.553 km for the total N, and 0.520 and 4.553 km for the available P for the top- and sub-soil depths, respectively. The calculation of the effective range is derived from a semivariogram, which is represented by the A_0. The zones of influence for the total N and the available P are smaller in the topsoil layer compared to the subsoil layer. This is expected due to the effect of fertilizer addition during the rice growing season. Similar studies on agricultural land[22-23] have all indicated that soil nutrient status may have a high spatial variance. The results shown in Table 2 indicate that the variability may even be higher on rice plantation. The short range of the both total N and the available P is probably due to the influence of crop and fertilizer management, which varied from field to field. The spatial dependence level (Table2) for the total N and the available P is considered weak and moderate for both top- and sub-soil depths, respectively. The results showed high nugget effects were found for all the parameters studied, indicating a high variability of the respective parameter between the sampling points.[24] For all parameters, smaller sampling should be recommended on this field in Figs 2 and 3 show the pattern of the semivariogram for the total N and the available P, respectively. So, future sampling for N should be done within 0.434 and 4.55 km for top and sub-layer, respectively, and for P should be done within 0.597 and 4.553 km for top and sub-layer, respectively.

We considered each depth as a discrete region. However, rice roots generally grow and interact with soil of all depths simultaneously. Hence, it would be logical to combine information over a super region, which would be defined as root zone. It was also observed that sill variance increased with depth for the total N, but not for the available P (Table 2).

Interpolation by Point Kriging

Figs 4, a and b, for the total N demonstrate the spatial pattern of total N concentration along the field for the top and sub-layer, respectively. In the top layer,

Table1. Statistical overview of some top- and sub-soil soil parameters measured in this study.

Parameter	Depth (cm)	Unit	Range	Std deviation	Variance	Median	Mean	CV %
N	0-20	%	0.50	0.087	0.0076	0.41	0.414	21
	20-30	%	0.53	0.0875	0.0076	0.32	0.329	26
P	0-20	mg/kg soil	129.76	22.45	504.40	45.95	50.20	44
	20-30	mg/kg soil	90.83	15.81	250.22	25.4	28.83	55

Table 2. Characteristic of calculated semivariogram of spatial soil fertility.

Parameter	Depth (cm)	Model	Range (A_o)	Nugget variance	Sill variance	Ratio nugget/sill	Spatial dependence
N	0-20	spherical	0.460	0.001	0.008	0.87	Weak
	20-30	linear	4.553	0.005	0.009	0.55	Moderate
P	0-20	spherical	0.597	69	491	0.86	Weak
	20-30	linear	4.553	173	316	0.45	Moderate

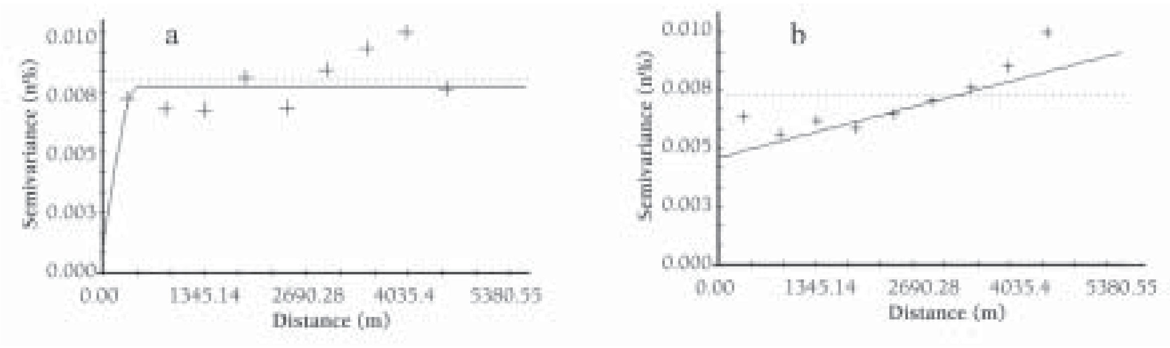

Fig 2. Computed semivariogram for total N for (a) top and (b) Sub-layer.

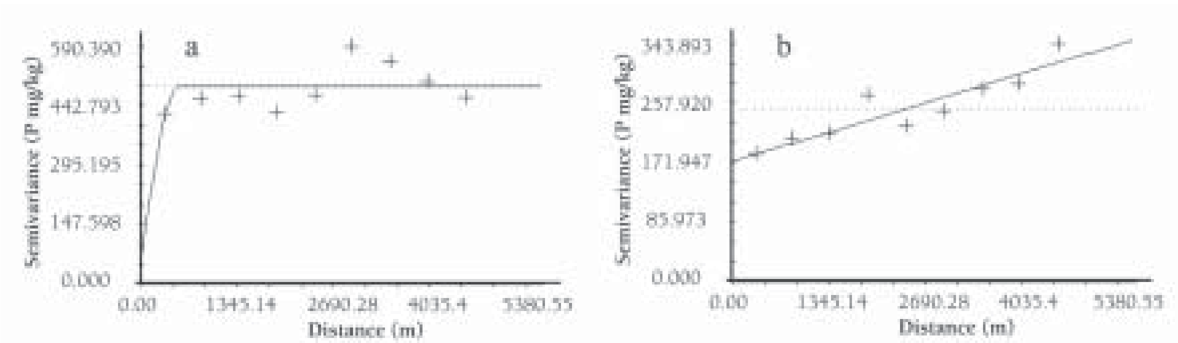

Fig 3. Computed semivariogram for available P for (a) top and (b) sub-layer.

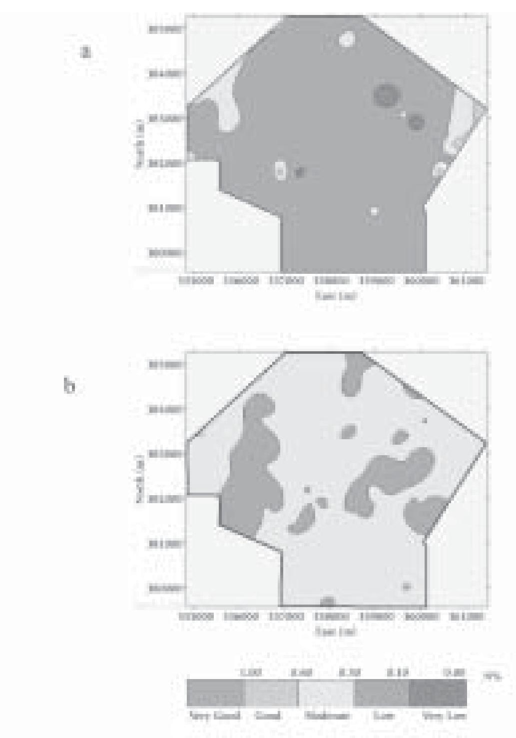

Fig 4. Variability map of total N for (a) top- and (b) sub-soil layer of Sawah Sempadan rice field.

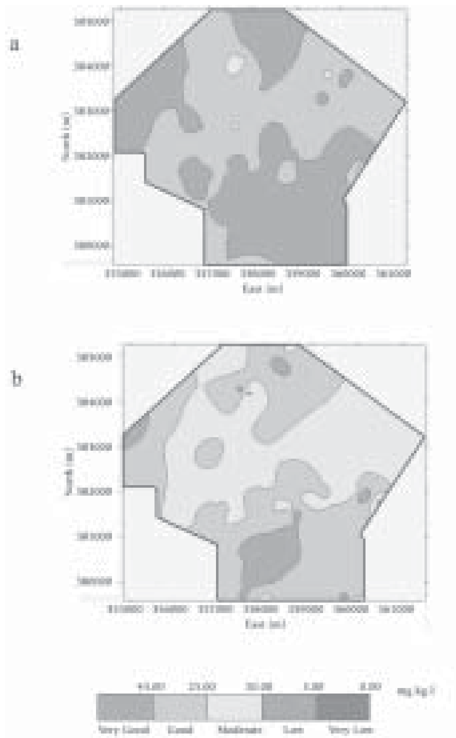

Fig 5. Variability map of available P for (a) top- and (b)sub-soil layer of Sawah Sempadan rice

low N concentration has covered most area of the field, with some moderate concentrations in the north and the east side of the field and good concentrations in the middle and the top right corner. In the sub-layer, moderate N concentration has covered most of the area of the field, and patches of low N concentration were found in the middle of the field and in the top and the right side of the field. When compared between the two layer, the concentration of the total N in the sub-layer is higher than that in the top layer. This is due to the high leaching of the nitrogen from the top layer.[25] The distribution of the available P is shown in Figs 5, (a) and (b), for the top and sub-layer, respectively. For the top-layer (Fig 5, a), the distribution of the available P varied, with mainly very good and good available P covering whole the field. A very good P is found at the bottom of the field and top left and right of the field, while the rest of the area contains good concentration of P with a very small and moderate concentration in the middle part of the field. For the sub-layer (Fig 5, b), moderate P concentration dominates in the middle and the top left right side of the field, whereas good P concentration covered the bottom and the top part of the field. Marx and Thompson[26] stated that krig-ing considered as a preferred method for analyzing spatial dependent data because it assures the return of observed sample values, is an unbiased estimation procedure, and provides a minimum estima-tion variance for each interpolated value.

The soil texture affects the soil nutrients, and there is little control over this property,[27] Fig 6 show the distribution of soil texture from the field. The area is classsified to be a clay according to USDA soil textural calssifi-cation. In clay soil , the clay particles are usually aggregated together into complex granules which enables it to hold more water and nutients than sandy soil.[27-28]

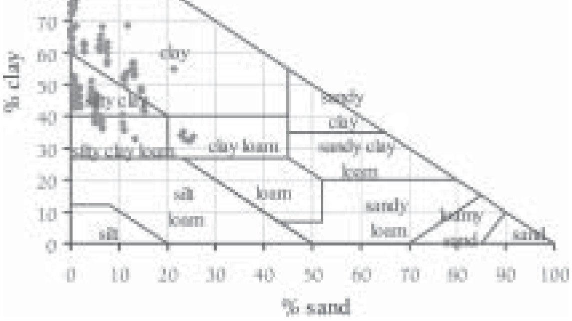

Fig 6. The distribution of soil texture in the field.

In the field that is used to apply N and P fertilizers without considerations to the variations exit in the area, the comparison of these fertilizer applications and these maps will help us understand the fertility status of the field.

Conclusion

This study analyzed the spatial variability in soil chemical properties, particularly the total N, the available P. The quantitative information obtained in this study could be used to facilitate site-specific management in Sawah Sempadan, Malaysia. The soil chemical properties usually have spatial dependence and understanding of such structure may provide new insights into soil behavior for site-specific management. Geostatistical techniques offer methods for the estima-tion of soil chemical properties and their associated variability. The semivariance analysis for all the chemical properties showed that the variability exits even within a small range. The spatial range of influence for the total N was 0.460 and 4.553 km for the top- and sub-soil depths respectively. The range for the available P was 0.597 and 4.553 km. for top- and sub-soil depth, respectively. The pattern of spatial variability in the form of kriging map may improve the decision for field management practices, such as fertilizer recommen-dation rate. Also knowledge of the variability in space and time of soil fertility such as the total N, and the available P, is one of the most important keys in further development of site-specific management. The most significant finding is the improvement of the nitrogen in the field should be done across many areas in the field in order to get maximum yield. Also the addition of both nitrogen and phosphorus fertilizer should be based on the detailed map generated by kriging.

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