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Spatial Variability of Selected Chemical Characteristics of Paddy Soils in Sawah Sempadan, Selangor, Malaysia

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ABSTRACT

A study was conducted to evaluate the spatial variability of selected soil chemical properties of paddy soils in the Barat Laut Paddy Project area in Selangor. A total of 138 geo-referenced soil samples were collected from the area at 0-20 cm depth after harvest, at an interval of 80-90 m to determine the selected chemical properties: pH, organic carbon, total nitrogen (N), available phosphorus (P) and exchangeable potassium (K). Geostatistical analyses were applied to examine the within-field spatial variability using semivariograms and kriged maps. Kriged maps for each property were prepared using geostatistical software package based on the results of spatial dependence. The effective ranges for the areas were about 6 km for pH, 1 km for organic carbon, 8 km for total N and available P and 9 km for exchangeable K, respectively. Kriged maps produced showed that most of the area have pH values within the range of 4-4.5 (moderately acidic) and high amount of organic carbon content (3-5%). The kriged maps also showed that a large portion of the study area (66%) have high total N (0.30-0.40%), with low amount of available P (< 40 mg kg-1) covering 70% of the total study area, while most of the area have optimum content of exchangeable K (> 0.10 cmol(+) kg^{-1}). These results suggest the need for a site specific approach in managing paddy soils particularly with regard to nutrient management. The results also suggested that future soil sampling in these area can be carried out by increasing the sampling interval depending on the soil properties, and appropriate management should be applied according to the variations which exist.

Keywords: Spatial variability, Geostatistics, Paddy soil, Chemical properties

INTRODUCTION

Fertilizer management is a major consideration in agricultural production. Inadequate fertilizer application limits crop yield, results in nutrient mining and causes soil fertility depletion. An excessive or imbalanced application not only wastes a limited resource, but also pollutes the environment. With consideration of both economic optimization and environmental concerns, farmers are forced to face with an ever-increasing demand for effective soil fertility management. An approach towards justifying such concerns is site specific nutrient management – which takes into account spatial variations in nutrients status cutting down the

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possibility of over or under use of fertilizer. There have been growing interests in the study of spatial variation of soil characteristics using geostatistics since 1970s, as geostatistics were well developed and successful in characterizing the spatial variations of heavy metals (Steiger *et al*. 1996; White *et al*. 1997; Yu *et al.* 2001; Romic and Romic 2003), micronutrients (Webster and Oliver 2001; Liu *et al*. 2004) and other soil characteristics (Yost *et al.* 1982; Yanai *et al*. 2001; Corwin *et al.* 2003; Mueller *et al*. 2003; Gilbert and Wayne 2008; Liu *et al.* 2008). Relatively few studies have thoroughly investigated the spatial variability of soil chemical characteristics in paddy field on a large scale (Yanai *et al*. 2000, 2001, 2002; Chen *et al*. 2002; Liu *et al*. 2008) and little information is available on the soil-related crop yield potential for monsoon Asia (Yanai *et al.* 2002). It was shown that the soil status of the major nutrients as well as organic matter and clay contents is spatially variable within a single small sized paddy field (Moritsuka *et al*. 2004). This author also found a spatial auto-correlation for most investigated soil parameters and concluded that a site-specific soil management would increase nutrient efficiency and crop productivity. The objectives for this study were (1) to determine the spatial dependency of the measured characteristics; and (2) to map the spatial distribution of each characteristic.

MATERIALS AND METHODS

Study area

Sawah Sempadan is located in the Barat Laut Paddy Project within the north of Selangor state which is in the southeast part of Malaysia (*Fig. 1*). The paddy soil is classified as Sedu Series (Typic Sulfaquepts) which is developed over brackish water deposits (Paramananthan, 2000). The selected area comprised of plots belonging to 54 farmers with a total hectarage of 70 ha with an average plot size of 1.2 ha or less. Fertilizer applications are limited to the farmers' perception, or at best, based on general recommendations provided by agricultural agencies. Global Positioning System (GPS) coordinates for the area is 3.730467^{o}N, 101.029567^{o}E *(Fig. 1*). A digital map for the area was constructed using DGPS Trimble Pro XR and GIS software. The GPS was used to record geographic coordinates of each corner of the plots and fence line during a site walk-through. The area map excluded housing area and other areas which were not cultivated with paddy. Every irrigation and drainage canals in the plot was also mapped. Sampling locations were later on-screen digitized on the area map with an average sampling distance of 80-90 m, to make sure that each sampling location are well distributed *(Fig. 2)*.

Soil sampling and analysis

Geo-referenced soil samples were taken from 138 locations within Sawah Sempadan area after harvesting season, prior to the area being burned to avoid errors from accumulation of ashes or effects of burning. The practice of burning is to prevent pest or disease outbreak from soil-borne pathogens. The soils has been

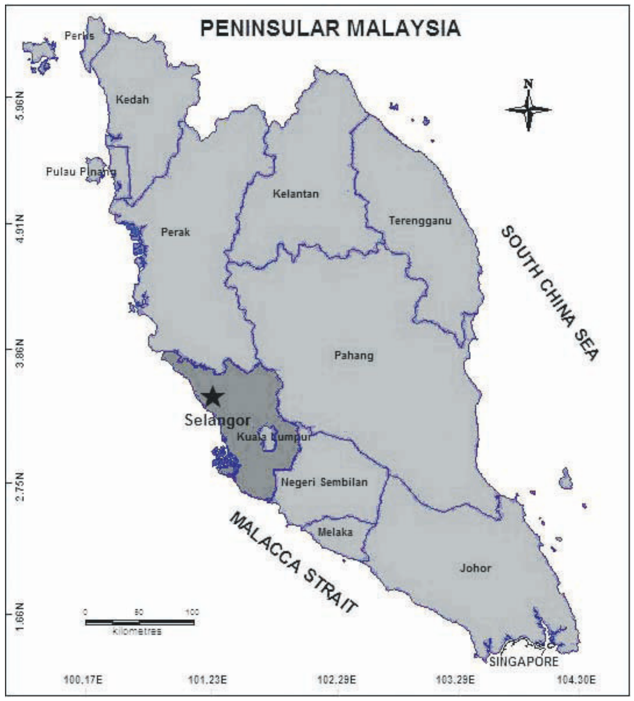

Fig. 1: Location of study area

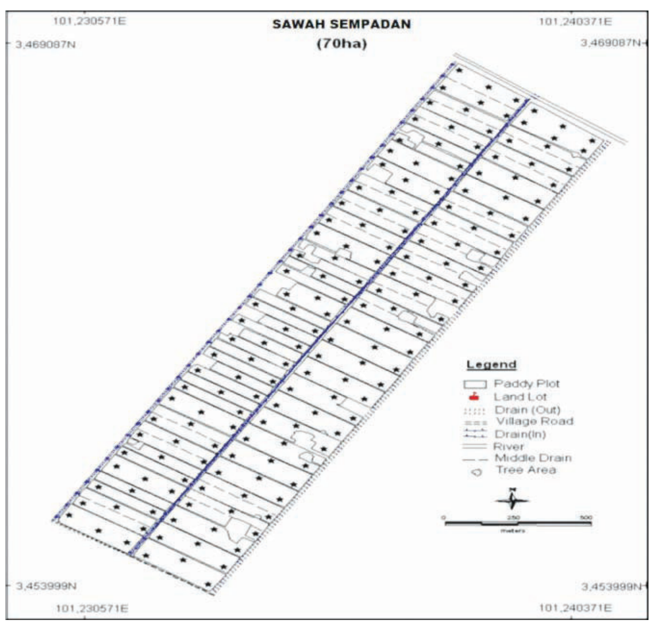

Fig. 2: Location of sampling points in paddy plots

drained, remain wet but non-saturated with 0-3 cm of the soils surface already beginning to dry. Another 30 geo-referenced soil samples were also randomly collected from the same area for data validation test. All the soil samples were taken at a depth of 0-20 cm with the soil surface cleared of coarse rice straw debris. Soil samples were air-dried, thoroughly mixed and ground to pass a 2 mm sieve, then stored in plastic containers prior to the analysis of soil pH, organic carbon (OC), total nitrogen (TN), available phosphorus (AP) and exchangeable potassium (EK). Soil pH was measured in a 1:2.5 (w/v) ratio of soil to water. Organic carbon was determined using the Walkley and Black method (Nelson and Sommers, 1982) and total N in the samples was determined by the Kjeldahl digestion method (Bremner and Mulvaney 1982). Available P was extracted using the Bray and Kurtz No. II extractant and determined using the Quickchem, FIA 8000 auto-analyzer (Lachat Instruments, Milwaukee, WI, USA). Exchangeable K was extracted with 1 M NH_4OAc, pH 7.0 using the leaching method and determined using the Perkin Elemer 5010 atomic absorption spectrophotometer.

Classical statistics

Data that were not normally distributed were logarithmically transformed in this study. It is shown in Table 1 that the data sets for all soil properties were normally distributed. Descriptive statistics, including the mean, range, standard error (SE), skewness and coefficient of variation (CV), were determined for each set of data. Pearson correlation coefficients were calculated to determine the relationship between soil properties.

Geostatistical analysis

Geostatistics is based on the theory of a regionalized variables (Matheron, 1963), which is distributed in space (with spatial coordinates) and shows spatial autocorrelation. Semivariogram were developed in this study to evaluate the degree of spatial continuity of each soil property. Information generated through variogram was used to calculate sample weighted factors for spatial interpolation by a Kriging procedure using the nearest 16 sample points and a maximum searching distance equal to the range distance of the variables (Isaacs and Srivastava 1989; Lark and Ferguson 2004). Kriging is a linear interpolation procedure that provides a best linear unbiased estimation for quantities, which vary in space. Kriging estimates are calculated as weighted sums of the adjacent sampled concentrations that is, if the data appeared to be highly continuous in space, then the points closer to those estimated received higher weight age than those further away (Cressie 1990).

Semivariogram, y(h), is computed as half the average squared difference between the components of data pairs (Burgess and Webster, 1980; Wang 1999; Goovaerts 1999), and is expressed using the following formula:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[Z(x_i) - Z(x_i + h) \right]^2$$

where N(h) is the total number of data pairs separated by a distance h; Z represents the measured value for soil property at the location of x. Several standard models are available to fit the experimental semivariogram, e.g., spherical, exponential, Gaussian, linear and power models (Oliver 1987; Isaaks and Srivastava 1989; Wang 1999). Using the fitted models, spatial interpolation was accomplished with a point kriging approach.

The levels for each variable on the spatial maps were set based on the standard range for paddy soil, recommended by Malaysian Agriculture Research and Development Institute (MARDI) in 2000. Cross-validation of kriged values were carried out based on the criteria proposed by Delhomme (1978) and Dowd (1984) and as explained in detail by Balasundram *et al.* (2008). Kriging was carried out using geostatistical software package to map the spatial patterns of each soil property. The validation test to evaluate the quality of produced maps was also conducted by comparing data values of each element from the 30 extra geo-referenced soils samples collected with the kriged values. The kriged values deviates from the samples' original values by only 1.76%, 3.41%, 1.9%, 4.12% and 2.23% for pH, organic carbon, total nitrogen, available P and exchangeable K, respectively.

RESULTS AND DISCUSSION

Descriptive statistics

Descriptive statistics results for each soil characteristic for 138 samples are presented in Table 1. These results indicated that all characteristics were normally distributed and showed wide variations. Except for pH and organic carbon, all other variables have CV values greater than 4%, the highest being 31% in the case of total N, suggesting that they had greater variation in the soils. This variation of soil chemical properties might be due to errors in measurements, soil properties, paddy variety, tillage practices, soil mineralogy, clay content, pesticide applications and moisture availability (Anuar *et al.* 2001).

In comparison to the optimum values of chemical characteristics for paddy requirement, as recommended by MARDI (Table 2), it is shown that the mean pH for the area is lower than the optimum range (5.5-6.5), while the mean concentration of organic carbon have already exceeded the optimum level (2-3%). The mean concentration of total nitrogen, available P and exchangeable K are within the optimum level for total nitrogen (0.2-0.3%), available P (> 40 mg kg^{-1}) and exchangeable K (> 0.1 cmol(+) kg^{-1}).

Geostatistical analysis results

The semivariograms and fitted models for each soil characteristic are presented in *Fig. 3*. The attributes of the semivariograms for each soil characteristic are summarized in Table 3. Nugget variance represents the experimental error and field variation within the minimum sampling spacing.

TABLE 1
Descriptive statistics of soils pH, organic carbon (OC), total Nitrogen (TN), available P (AP) and exchangeable K (EK)

Characteristic	Sample size	Mean	Skewness	SE	CV (%)
pH	138	4.70	0.051	0.014	4
OC (%)	138	4.06	2.587	0.003	1
TN (%)	138	0.43	1.54	0.010	31
AP (mg kg^{-1})	138	43.18	0.487	0 .009	29
EK (cmol(+) kg^{-1})	138	0.25	-0.69	0.004	24

SE standard error, CV coefficient of variation

TABLE 2
Optimum soils chemicals properties values for paddy requirement

1. pH	5.5 – 6.0
2. Organic Carbon (%)	2 – 3
3. Total Nitrogen (%)	0.2 – 0.3
4. Available P (mg kg^{-1})	> 40
5. Exchangeable K (cmol + kg^{-1})	> 0.1

(Source: MARDI, 2000)

Spatial class ratios (Nugget/Sill ratio) similar to those presented by Cambardella *et al*. (1994) were adopted to define distinctive classes of spatial dependence. A variable is considered to have a strong spatial dependency if the ratio is less than 25%, moderate spatial dependency if the ratio is between 25-75% and weak spatial dependency if the Nug/Sill ratio is greater than 75%. In addition, spatial dependence is defined as weak if the best-fit semivariogram model has an $R^2 < 0.5$ (Duffera *et al.* 2007). Cambardella *et al.* (1994) also reported that strong spatial dependency of soil characteristics can be attributed to intrinsic factors (soil formation factors, such as parent materials), and weak spatial dependency can be attributed to extrinsic factors (soil management practices, such as fertilization).

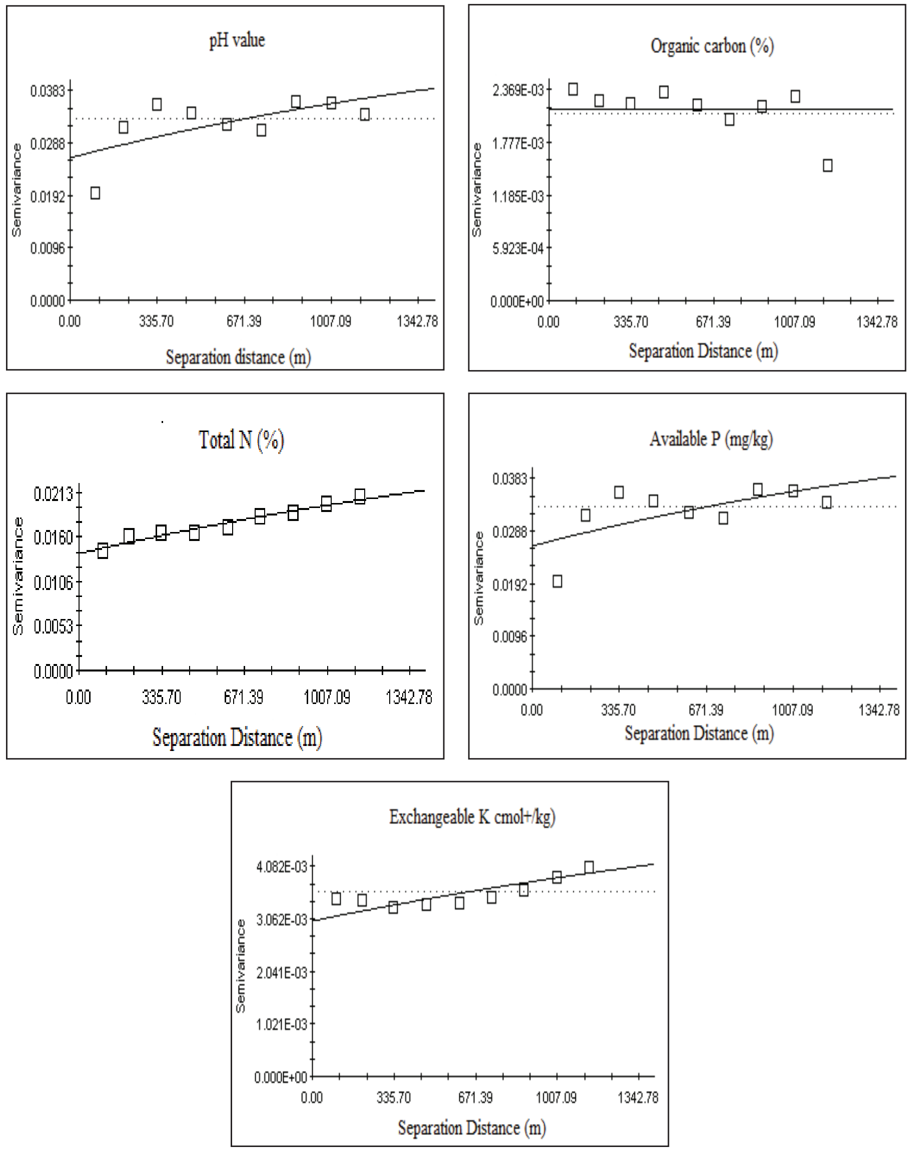

Fig. 3: The semivariograms of soil pH, organic carbon (OC), total N (TN), available P (AP) and exchangeable K (EK) at Sawah Sempadan

The semivariograms for soil pH, total N, available P and exchangeable K were all fitted to exponential model and their Nugget/Sill ratios were 50, 58, 50 and 50%, respectively, indicating the existence of moderate spatial dependency. These suggest that the extrinsic factors such as fertilization, plowing and other soil management practices weakened their spatial correlation after a long history of cultivation. Soil pH, total nitrogen (TN), available P and exchangeable K (EK)

TABLE 3
Best-fitted semivariogram models for soil pH, organic carbon (OC), total Nitrogen (TN), available P (AP) and exchangeable K (EK) and their parameters

Characteristic	Model	Nugget C_o	Sill C_o+C	Nug/Sill ratio (%)	Spatial Classes	Effective Range (m)	R^2
pH	Exponential	0.026	0.052	0.50	M	6327	0.39
OC (%)	Linear	0.002	0.002	1	-	1137	0.42
TN (%)	Exponential	0.014	0.033	0.58	M	8394	0.95
AP (mg kg^{-1})	Exponential	132.4	264.9	0.50	M	8205	0.47
EK ($cmol_+$ kg^{-1})	Exponential	0.003	0.006	0.50	M	9330	0.59

all had long effective spatial correlation range. The spatial ranges of soil pH and total nitrogen in Sawah Sempadan were 6320 m and 8390 m, respectively. For available P and exchangeable K, its effective spatial correlation distances were 8200 m and 9330 m, respectively. This result indicates a rational sampling distance for soil pH, total nitrogen, available P and exchangeable K within their effective spatial correlation ranges in Sawah Sempadan.

However, soil organic carbon did not show a scale of dependency, which indicates that soil management practices greatly affected soil organic carbon and reduced spatial dependency at the sampling intervals. This indicates that 138 samples are not sufficient to describe their true characteristics. Therefore, it was reasonable to predict the spatial distribution of all soil characteristics with the exception of organic carbon at Sawah Sempadan due to their high spatial dependency. In other words, the results also showed that with the exception of soil organic carbon, the range of exponential models which exceeded 80-90 m indicated the presence of spatial structure beyond the original average sampling distance. When cross-validated, data from each soil property measured showed acceptable accuracy.

Spatial Distributions

The main application of geostatistics to soil science has been the estimation and mapping of soil attributes in unsampled areas. *Fig. 4* presents the spatial distributions of each soil characteristic in Sawah Sempadan area generated from their semivarograms. The prediction maps of soil pH, organic carbon, total nitrogen, available P and exchangeable K were generated using ordinary Kriging methods with original values of soil pH, organic carbon, total nitrogen, available P and exchangeable K.

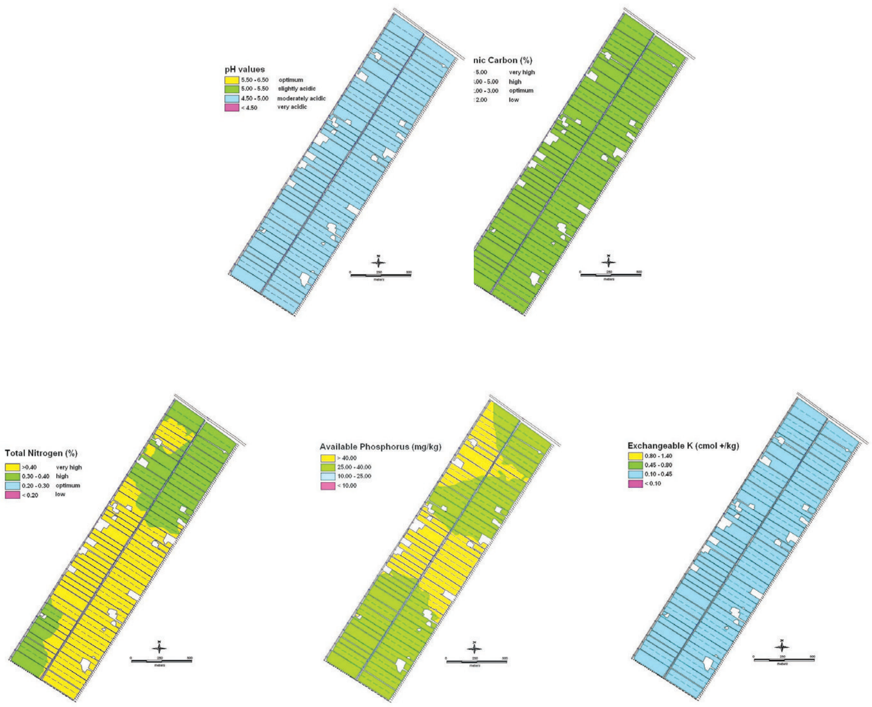

Fig. 4: The distribution maps of soil pH, organic carbon (OC), total N (TN), available P (AP) and exchangeable K (EK) at Sawah Sempadan

The correlation between each soil characteristics were analyzed to understand their effect on each other (Table 4). Organic carbon (r=0.23) were found to be positively correlated with total nitrogen and exchangeable K were in positive correlations with available P (r=0.37).

The maps show that 100% of the area has pH values of 4.5-5.0 which is considered as moderately acid. The optimum pH values as recommended by MARDI are within the range of 5.5-6.5. The area has high organic carbon content within the range of 3-5%. The addition of organic carbon was through the addition of organic matter in the form of plant residue (rice straws) and the slow decomposition of organic matter owing to the soil always remaining wet most of the time. Of the total area, 46.5 ha showed very high total nitrogen content while the other 23.5 ha have high total nitrogen content which ranges between 0.3-0.4%. High content of total nitrogen are also related to the addition of organic matter in the form of plant residues.

Seventy percent (49.01 ha) of the total area shows available P values lower than 40 mg kg^{-1}. The other 20.99 ha shows available P values higher than 40 mg kg^{-1} which is considered as optimum based on the recommendation by MARDI. The whole study area shows optimum conditions for exchangeable K (> 0.1

cmol(+) kg^{-1}). The variability among all these soil characteristics might probably be due to the difference between various soil management practices by farmers.

TABLE 4
Pearson correlation coefficients between soil characteristics

Characteristic	pH	OC	TN	AP	EK
pH					
OC	0.004ns				
TN	0.025ns	0.216*			
AP	0.086ns	0.049ns	0.037ns		
EK	-0.023ns	-0.075ns	0.049ns	0.175*	

* P<0.05

From the maps of soil characteristics, information about their spatial distribution over long distances could be clearly achieved. The rice fields in Sawah Sempadan may be classified into soil groups according to similar soil nutrients concentrations (N, P and K). Appropriate fertilization is recommended for different groups, which will make the soil management more scientific. The results of this study can also be used for soil survey and evaluation.

It is also found that the sampling interval could be increased in future studies depending on the soil characteristics. Based on the variability existed, it is strongly recommended that site specific nutrient management should be carried out in Sawah Sempadan area with more emphasis on P nutrient and increasing pH values to the optimum level of pH required for paddy production which is between pH 5.5 to 6.0. As suggested, the variability of each soil characteristic existed due to the differences in management practices by farmers. Therefore, the fertilization plan of an individual farmer should take into account this variability to optimize nutrient application rates for better yield and economics of crop production.

CONCLUSIONS

This study reveals major variability in terms of soil nutrients status in the 70 ha area in Sawah Sempadan. Spatial maps produced showed that the area in Sawah Sempadan has high organic carbon content (3-5%), with total nitrogen value already exceeded the optimum values required for paddy (2-3%) and optimum conditions for exchangeable K (> 0.1 cmol(+) kg^{-1}). However, pH ranges for the whole area is still below the optimum pH ranges (5.50 – 6.50) required, and 70% of the area still has available P values lower than the optimum value (< 40 mg kg^{-1}).

The results suggested that pH, total N, available P and exchangeable K had moderate spatial dependence over a long distance; suggesting that extrinsic factors such as fertilization, plowing and other soil management practices weakened their spatial correlation after a long history of cultivation. The spatial ranges for pH, total N, available P and exchangeable K were about 6, 8, 8 and 9 km, respectively. However, the semivariogram for organic carbon did not show any scale of dependency which could be due to fertilization practices. This indicates that more samples should be taken at smaller sampling intervals in the area to determine the spatial dependency for heterogeneous data. The semivariogram of organic carbon was fitted to the linear model with a range of 1 km.

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