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Full Length Research Paper

Spatial variability of Cu, Mn and Zn in marginal sandy beach ridges soil

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The concentrations of Mn, Cu and Zn in marginal sandy soils were spatially heterogeneous. The objective of presented study were i) to quantify the variability of Mn, Cu and Zn concentration in marginal sandy soil; and ii) to develop the pattern of that variability in kriged maps. The georeferenced soil samples (n = 26) were taken at 0 to 15 and 15 to 30 cm depths from the experimental site located at Telaga Papan Setiu, Terengganu, Peninsular Malaysia. Soil samples were analyzed for extractible Mn, Cu and Zn and spatial variability was quantified with the geostatistics. Co-efficient of variation ranged from 31 to 75% indicating the heterogeneity of Mn, Cu and Zn in soil and spatial ranges varied from 495 to 2110 m in the studied area. The geostatistical analyses showed a definable spatial structure for Mn, Cu and Zn at both the depths. Cross validation test showed accurate interpolation and 26% of the data were positively correlated for Mn, Cu and Zn in the sandy soil. Kriged maps of marginal sandy area indicated that >50% area was high in Mn content at both the depths. Very high content of Mn were found in 6.8 ha of top soil and 9.5 ha of sub soil. Maps for the Zn content showed that >50% area was low at surface and medium at lower depth of sandy soil. Study concluded that quantification of Mn, Cu and Zn variability would assist in planning of future soil sampling as well as site specific management zone based strategies for crop production on these marginal sandy soils.

Key words: Sandy beach ridges soil, spatial variability, geographic information system, Cu, Mn, Zn, geostatistics, spatial distribution maps.

INTRODUCTION

Sandy lands are generally considered to require homogenous management practices that induce considerable variability and reduction in cationic micronutrients content (Cu, Zn and Mn) (Pegoraro et al., 2006). Marginal sandy beach ridges soils are running parallel to the east coast of Peninsular, Malaysia (Roslan et al., 2010) comprising 90% sand, low in water holding capacity, low in nutrients and organic matter content (Shamshuddin, 1990). These soils are difficult to develop for agriculture due to low fertility level and high inputs for development (Roslan et al., 2010). Question is often raised about the relative importance of micronutrients in crop production. They are present in small quantities in the soil and most of the field crops are sensitive to deficiencies of Cu, Mn and Zn. The deficiencies of Mn, Cu, and Zn are mainly reported on sandy soils that are low in organic matter (Verma et al., 2005). For more than three decades variety of plant and animal manures have been applied for the management of these marginal sandy soils for tobacco production. Khairuddin and Kamaruddin (1981) reported that tobacco yield was increased by 40% with the liming at a rate of 2500 kg ha^{-1} on the other hand it reduces the availability of micronutrients in the soil (Pegoraro et al., 2006). About 30 to 50 metric ton ha^{-1} $year^{-1}$ of palm oil mill effluent (POME) is recommended for tobacco production on these marginal soils (Vimala et al., 1990) but the application of trace elements have not been considered yet. Dhane and Shukla (1995) concluded that judicious use of nitrogenous and phosphatic fertilizers in the intensive cropping system may cause the quick depletion of micronutrients in soils. The management practices involved ploughing, harrowing and addition of plant

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nutrients from organic and inorganic sources are positive assets if retained in the soil for uptake by plants, but become environmental pollutants if leached into ground waters (McGechan and Lewis, 2000) and may induce variability in soil Mn, Cu and Zn which ultimately effects on crop yields. Recent modern technologies such as remote sensing, DGPS, GIS and geostatistics are playing a vital role for quantifying spatial variation and interpolation of soil characteristics. In Malaysia various studies have been conducted for spatial-temporal yield trends in oil palm (Anuar et al., 2008) and spatial variability studies in paddy fields (Aimrun et al., 2010) and peat soil (Balasudram et al., 2008) have also provided the basic information for the implementation of precision farming in most parts of the country. Land scarcity is the main cause which drives the research efforts to focus on the marginal sandy areas for crop production in Peninsular Malaysia. For the sustainability of agricultural environment Mn, Cu and Zn in sandy soil need to be measured spatially. The objective of presented study were i) to quantify the variability of Mn, Cu and Zn concentration in marginal sandy soil; and ii) to develop the pattern of that variability in kriged maps.

MATERIALS AND METHODS

The study was conducted in May 2008 geographically located at 5°30`51.29`` North 102°54`03.05`` East Telaga Papan Setiu, Terengganu, Peninsular Malaysia (Figure 1). Differential global positioning system (Trimble Pro XR) was used to get the boundary of 21.9 ha area. Annual mean temperature of the study area is 26°C and 2723 mm rainfall which cause flooding during the monsoon season (DOA, 2009). Soil samples were collected geostatistically at 0 to 15 cm and 15 to 30 cm depths with stainless steel auger. Soil samples were air-dried, sieved through 2 mm sieve and kept in plastic bottles. Mn, Cu and Zn in the soil samples were extracted with double acid method (Benton Jones, 2001) followed by Perkin Elmer 5010 atomic absorption spectrophotometer. The descriptive statistics maximum, minimum, mean, standard deviation and co-efficient of variation were calculated for each soil variable. Data were also explored for correlation and paired t-test with SAS software version 9.2. The spatial pattern of extractible Mn, Cu and Zn was determined by geostatistical analysis with GS+ software. A semivariogram for CU, Mn and Zn at both the depths was calculated as described by Goovaerts (1997):

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [Z(xi + h) - Z(xi)]^2$$

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 (Vauclin et al., 1983). Spherical, exponential, linear, linear to sill and gaussian models were tested for the best fit spatial structure of each soil property. All the soil variables were ranged in five classes as the interpretation values described by (Benton Jones, 2001). Best fit model was selected on the basis of lowest residual sum of square (RSS) and maximum co-efficient of determination (R^2). Spatial dependence was classified by nugget to sill ratios described by Cambardella et al. (1994). A ratio less than 25% indicate strong spatial dependence, between 25 to 75% shows moderate spatial dependence and more than 75% indicates weak spatial dependence. The kriged maps were digitized by Mapinfo software at GIS platform. Kriged values were cross-validated proposed by (Webster and Oliver, 2007; Balasundram et al., 2008). Firstly, the interpolation mean error (ME) should be close to zero, where, n is the number of sampling points, Z is the predicted value of the variable at point x_i and z (x_i) is the measured value of the variable at point x_i.:

$$\mathrm{ME} = \frac{1}{n}\sum_{i=1}^{n}\left[\bar{z}(x_i) - z(x_i)\right]$$

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}\left[\bar{z}(x_i) - z(x_i)\right]^2$$

$$\mathrm{SMSE} = \frac{\frac{1}{n-1}\sum_{i=1}^{n}\left[\bar{z}(x_i) - z(x_i)\right]^2}{\sigma^2}$$

Secondly, the mean squared error (MSE) should be less than the sample variance. Thirdly, the ratio of the theoretical and calculated variance, called the standardized mean squared error (SMSE), should be approximately close to one.

RESULTS AND DISCUSSION

Descriptive Statistics

The overview of the descriptive statistics for Cu, Mn and Zn showed a moderate co-efficient of variation (Table 1). Highest CV of 75.6% was observed for Zn at 0 to 15 cm depth and lowest CV 31.1% was observed for Cu at 15 to 30 cm depth (Table 1). Results indicated that CV was in decreased order of Zn>Cu>Mn at the surface of sandy soil with the agreement of results reported by (Wall and Marsh 1988; Wopereis et al. 1988). At the lower depth of sandy soil the CV was in decreased order of Zn>Mn>Cu (Table 1).The wide range of CV for the study area indicating heterogeneity of Mn, Cu and Zn at the studied area. Mn had the highest mean value (1.41 ppm) while Cu had the lowest mean value of (0.77 ppm). Mean Cu content for sandy soil was significantly higher at top soil as compared to sub-soil but there was no significant difference was observed for Mn and Zn at both the depths (Table 1). A wide range of Zn content was observed at the surface of sandy soil and a narrow range was observed for Mn content at sub-surface of sandy soil (Table 1). The correlation among Mn, Cu and Zn showed that Zn was positively correlated with Mn ($r = 0.46$) at upper depth as well as with Cu ($r = 0.37$) at lower depth (Table 2). Correlation among Mn, Cu and Zn indicated that 26% of the data were positively correlated and remaining 74% did not show a significant degree of correlation (Table 2).

Geostatistical analyses

The attributes of the geostatistical analyses (Table 3)

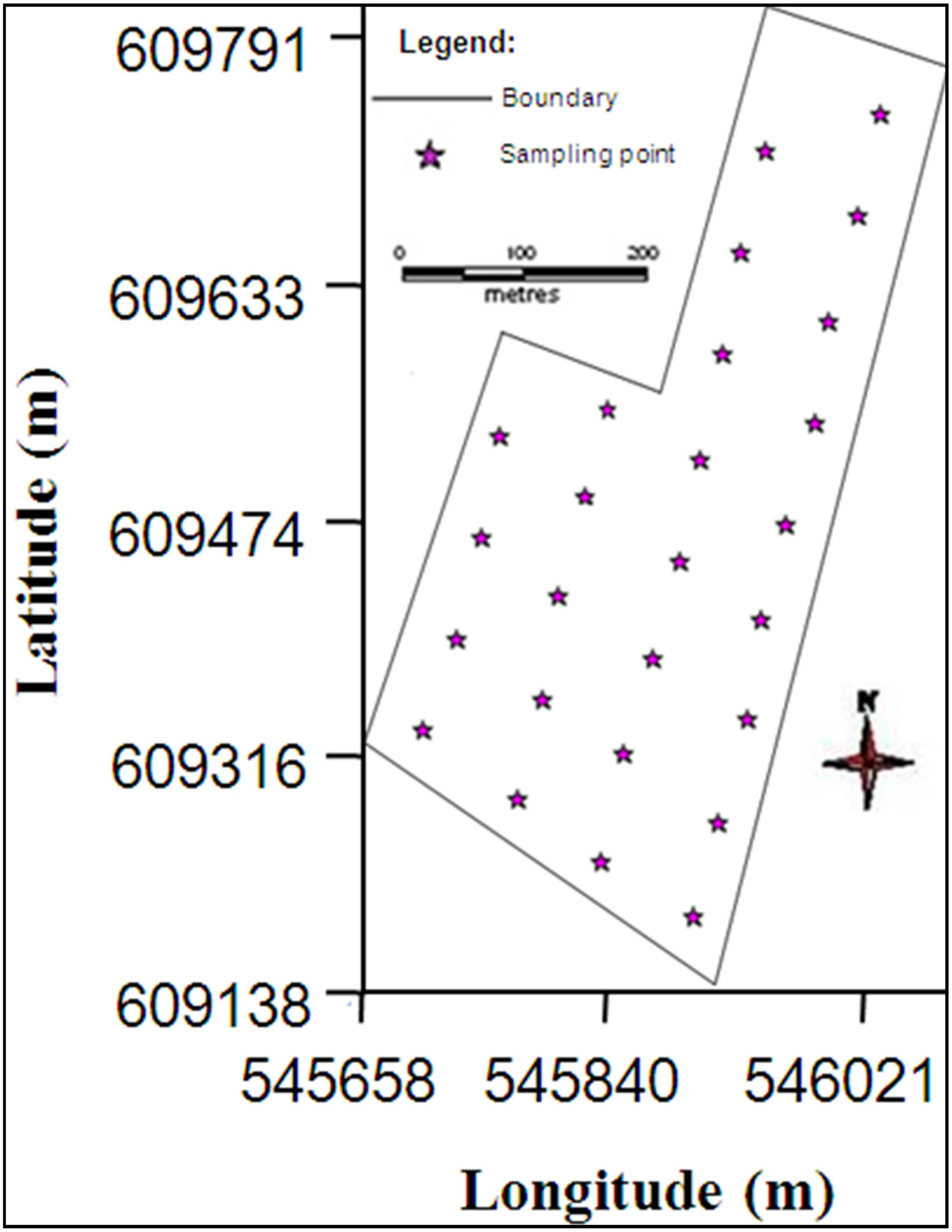

Figure 1. Location of sampling points in study area.

showed a definable spatial structure for Mn, Cu and Zn at both the depths of sandy soil. The Cu and Zn were modeled with spherical model at surface whereas Mn also fitted with the same model at sub-surface of the sandy soil (Table 3). At sub-subsurface Cu and Zn were modeled with exponential model while Mn was fitted with Gaussian model at surface of the sandy soil (Table 3). The co-efficient of determination for Mn, Cu and Zn ranged from 0.35 to 0.90 indicating a definable fit of models for both the depths of sandy soil.

The range expressed as distance, and can be interpreted as the diameter of the zone of influence, which represents the average maximum distance over which a soil property of the two samples is related. Spatial ranges of Mn, CU and Zn varied from 495 to 2110 m in the studied area. Mn and Zn had higher ranges at

Table 1. Descriptive statistics for manganese (Mn), copper (Cu) and zinc (Zn) at 0-15 and 15-30 cm depths of soil.

Variable	Depth	Mean	SD	Min	Max	CV%
Mn	0-15	1.41[a]	0.6	0.55	2.66	42.55
	15-30	1.09[a]	0.53	0.34	2.09	48.62
Cu	0-15	1.21[a]	0.53	0.22	2.55	43.80
	15-30	0.77[b]	0.24	0.18	1.28	31.16
Zn	0-15	1.15[a]	0.87	0.21	3.31	75.65
	15-30	0.82[a]	0.55	0.14	2.14	67.07

SD = Standard deviation; CV = coefficient of variation.

Table 2. Correlation among manganese (Mn), copper (Cu) and zinc (Zn) at 0-15 and 15-30 cm depths of soil.

Var	Mn1	Mn2	Cu1	Cu2	Zn1	Zn2
Mn1	1.0					
Mn2	0.05	1.0				
Cu1	-0.13	0.22	1.0			
Cu2	-0.13	-0.07	0.68**	1.0		
Zn1	0.46*	-0.16	0.17	0.14	1.0	
Zn2	0.30	-0.03	0.37*	0.21	0.76**	1.0

1 = Top soil, 2 = sub soil, *P = 0.05 ; ** P = 0.01.

Table 3. Geostatistical analysis for Manganese (Mn), Copper (Cu) and Zinc (Zn) at 0-15 and 15-30 cm depths of soil.

Variable	Depth	Model	C_o	C_o+C	A_o	R^2	Nug:Sill	SC
Mn	0-15	Gaussian	0.20	1.62	967	0.43	12.35	S
	15-30	Spherical	0.0001	0.29	495	0.60	10.03	S
Cu	0-15	Spherical	0.19	0.51	1141	0.90	37.25	M
	15-30	Exponential	0.08	0.18	2110	0.35	44.44	M
Zn	0-15	Spherical	0.21	1.5	1069	0.87	14.00	S
	15-30	Spherical	0.20	0.43	1169	0.35	49.00	M

C = Structural variance; C_0 = nugget variance; A^0 = range; SC = spatial class; S = strong, M = medium.

top soil as compared to sub-soil except Cu had higher range at subsurface of sandy soil (Table 3). The results indicated that Mn and Zn were strongly spatially dependent, with nugget-sill ratios ranged from 10.03 to 14.00 and Cu was moderately spatially dependent (Table 3). The moderate spatial dependence for Cu indicates that structural factors may influence on its spatial variability (Cambardella et al., 1994). Soil properties may vary at different scale of spatial resolution in the landscape as well as within a single filed Bergstrom et al. (2001). Strongly spatial dependence for Mn and Zn and moderate spatial dependence for Cu is expected due to the effect of fertilizer addition at the studied area; however similar studies on agricultural land (Eltaib et al., 2002; Ruhling et al., 1997) have indicated that soil nutrient status may have a high spatial variance. The components of cross validation test indicated that the interpolation for all the soil variables was almost accurate for distribution maps. The mean error of the entire soil variable was close to zero as well as mean squired error was also lower than the sample variance of all soil variables (Table 4). The results of cross validation test

Table 4. Cross validation test for manganese (Mn), copper (Cu) and zinc (Zn) at 0-15 and 15-30 cm depths of soil.

Variable	Depth	Sample variance	ME[1]	MSE[2]	SMSE[3]
Mn	0-15	0.37	0.01	0.39	1.07
	15-30	0.28	0.02	0.33	1.09
Cu	0-15	0.27	0.0	0.28	1.00
	15-30	0.07	-0.01	0.06	1.07
Zn	0-15	0.65	-0.02	0.67	0.90
	15-30	0.32	0.02	0.30	1.11

[1]Mean error, [2]mean squired error, [3]standardized mean squared error.

clearly showed that the standardized mean squared error for Mn, Cu and Zn was close to one indicating the accuracy of the interpolation (Table 4).

Spatial distributions

The main application of geostatistics is the estimation and mapping of soil properties at unsampled locations. The spatial distributions of Mn, Cu and Zn generated from their semivariograms are presented in Figure 2. The prediction maps of Mn, Cu and Zn were generated using ordinary kriging methods with their original values. The kriged maps showed that >50% area was high in Mn content at both the depths. At surface Mn were found very high in 6.8, high in 9.5 and medium in 5.6 ha; while at sub-surface it was higher in 12.1 and medium in 9.8 ha respectively (Figure 2). Maps showed that Cu was medium in 2.5 ha at top soil and completely low at sub soil (Figure 2). Maps for the Zn content showed that >50% area was low at surface and medium at lower depth of sandy soil. Maps showed very high content of Zn in an area of 0.6 ha at surface and 0.2 ha at sub surface of the studied area (Figure 2). An increase in sand content of soils resulted in a decrease in the availability of Mn, Cu and Zn were observed by Verma et al. (2005). The variation in Mn, Cu and Zn content of sandy soil at both the depths could be cause of disturbance; where heavy machinery has been used for the conversion of studied area from tobacco to kenaf cultivation. Katyal and Sharma (1991) explained that pedospheric variations due to topography, climate and parent material lead to spatial variation of Mn, Cu and Zn in soils. The disturbance of three decades old soil management system could be the cause of Mn, Cu and Zn variability at the studied soils. Trangmar et al. (1987) reported that land clearing by bulldozing and burning resulted in exposure of acid subsoil increase spatial variability of soil properties. Outcome of this study shows the medium spatial dependence of Mn, Cu and Zn in soils is directly influenced by random factors (including management practices) and structural factors (Cambardella et al., 994; Goovaerts, 1997). Values for soil Mn, Cu and Zn in

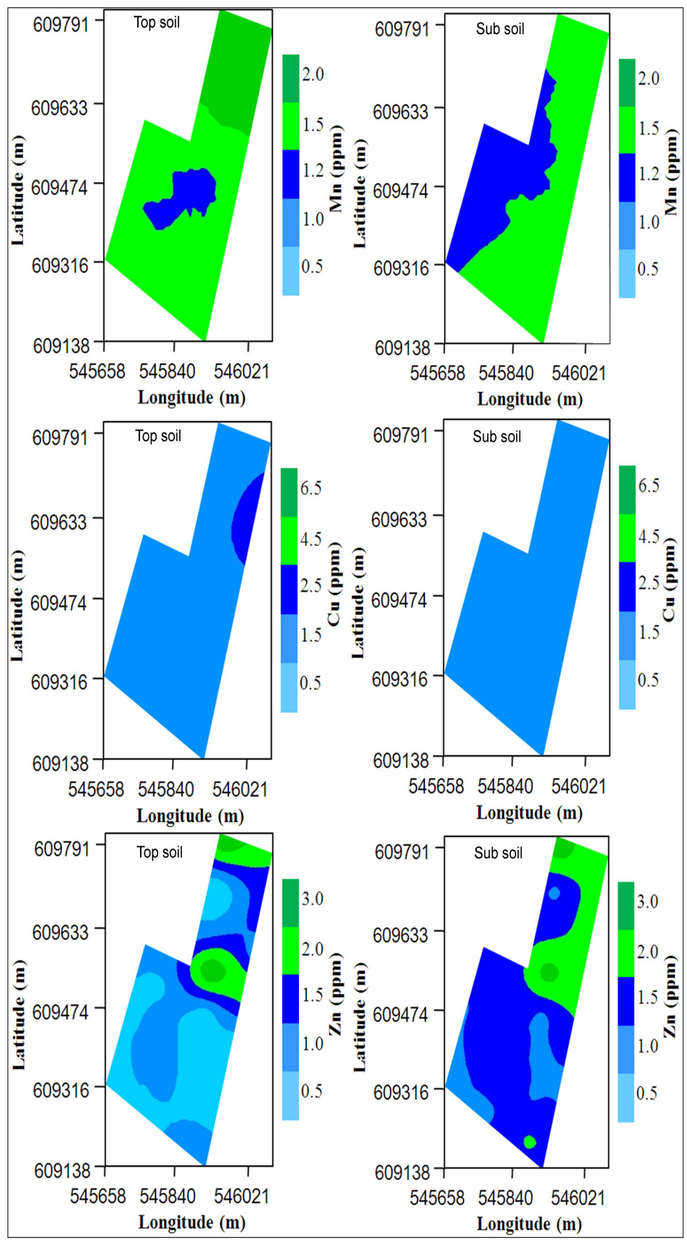

Figure 2. Spatial distribution maps of Cu, Mn and Zn at top and sub soil.

soils can be predicted for the majority of locations in the region where the values are not actually measured (Burgess and Webster, 1980).

Conclusion

It is concluded that classical statistics explained considerably about the variability of Mn, Cu and Zn at the studied area. Further understanding of spatial characteristics for Mn, Cu and Zn has been explained by the geostatistics. Study concluded that quantification of spatial variability of Mn, Cu and Zn would assist in planning of future soil sampling strategies where site specific management zone based strategy is required for the sustainable crop production on marginal sandy soils.

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