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Geostatistical Study of Surface Soil Properties Under an Oil Palm Plantation: 1 Semi-variogram

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Abstract

The spatial variability of selected surface soil properties was studied under an oil palm plantation by using geostatiscal concepts. Measurement were made on samples collected at 10 metres interval on a 10m x 10m grid from a plot of one hectare. Semi-variograms of the soil properties were computed and fitted to appropriate models by the least square method. This showed the variabilities in the soil properties to be anisotropically spatially structured. Cross-variograms were also presented for gravel content, bulk density and cone index. The usefulness of this technique as aid in identifying the cause and the nature of variabilities in soil properties are discussed.

Introduction

Quantitative evaluation of soil resources and their responses to management requires precise information on the spatial variability of soil properties. The Fisherian statistical procedures which assume that observed variations are random and independent of locations have been employed in this regard. These assumptions however, make the classical models, such as moving average, spline interpolation and trend analysis among others, inadequate for interpolation of spatially dependent variables. Geostatistical techniques, which is based on the theory of regionalized variables (Matheron, 1971) provides a tool for the quantitative evaluation of the spatial dependence of soil properties and can be used for interpolation of the spatially dependent variables. The Variogram which is the central tool of geostatistics, has variously been used (Webster, 1985; Uehara et al, 1985; and Oliver, 1987) to quantify the scale and intensity of spatial variation and to provide information for interpolation by Kriging and optimization of sampling intensity. This paper reports the use of semi-variogram to evaluate the spatial dependence of selected soil physical properties and the use of cross-variogram to explain the spatial relation or inter-dependence between pairs of soil properties under an oil palm plantation.

Material and Method

This study was conducted on a 2-hectare oil palm plantation, situated on a gentle slope (2 - 5%) in the teaching and research farm of Obafemi Awolowo University, Ile-Ife. The soil is classified as Iwo series, which is an Ultisol derived from coarse grained granite gneiss (Smyth and Montgomery, 1962; Okusami and Oyediran, 1985). A plot of 100m by 100m was chosen within the field, and core samples of surface (0 - 10cm) soils were collected on grid points on a 10m x 10m grid. Three replicate samples were collected at each sampling point. The gravel and field capacity moisture content of the soil samples were determined. In addition cone index was evaluated for the sampled points with the aid of a portable cone penetrometer.

The VAR 5 subroutine of the geostatistical software developed by the Department of Agronomy and Soil Science, University of Hawaii, USA, was used for the computation of variogram and cross-variogram. The semi-variances were computed for the three soil properties and cross semi-variances were estimated for these soil properties. These variograms were fitted to the appropriate models using the least square regression method (Cressie, 1985).

Theory

The principal tool of geostatistical analysis is the semi-variogram. This function relates the similarity or difference, expressed as the semi-variance between values at different places to their separation distance (lag) and direction. This theory is based on the assumption that the properties to be evaluated (soil properties) are locally stationary (Webster and Burgess, 1980). Given this basic assumption of stationary, semi-variances can be estimated using the formula:

$$y(h) = \frac{1}{2N(h)} \sum [[Z(X_i) - Z(x_i + th)]^2] \quad \ldots\ldots 1$$

where Z (X) and Z (X + h) are the values of a random function representing the soil property of interest, Z, at places x, and (x + h) separated by the vector h, known as the lag. The number of pairs of observation is represented by N (h).

Similarly, cross-variograms may be computed to evaluate spatial co-variation or interdependence between any two soil properties using the formula:

$$y_{A,B}(h) = \frac{1}{2N(h)} \sum [[XA(X_i th] [ZB(X_i) - ZB(x_i th)]] \quad \ldots\ldots 2$$

Where $y_{A,B}$ is cross-semi-variance between any two soil properties A and B as a function of the lag (h), $Z_A(X_i)$ and $Z_A(X_i + h)$ are values of the soil property A at locations Xi and (Xi + h), while $Z_B(X_i)$ and $Z_B(X_i + h)$ are the values of the soil property B at locations X_i and $(X_i + h)$.

Results

The means of the three soil properties are provided with their associated parameters in Table 1. The semi-variograms of the soil properties evaluated at different directions are shown in Fig 1. These semi-variograms exhibited strong anisotropy, with anisotropic ratios of 1.25, 3.60 and 3.74 for cone index, moisture content and gravel content respectively. The soil variability was generally highest in the NW-SW

TABLE 1: SUMMARY OF STATISTICS

Soil Property	No. of Samples	Mean (X)	S. E.	Variance (S^2)	CV
Gravel Content (%)	121	18.38	9.43	89.01	51.33
Moisture Content (%)	121	20.78	5.51	30.40	26.64
Cone Index (Kg/cm^2)	121	10.40	5.08	25.76	48.80

TABLE 2: SPATIALLY DEPENDENT PARAMETERS OF THE SOIL PROPERTIES

Soil Property	Range (a)	Sill ($C_o + C_1$)	Nugget as % Sill	Nugget as % of S^2	Vario-gram
Gravel Content %	38	85	10.14	5.08	Hyper-bola
Moisture Content %	36.5	29.5	9.49	9.21	Hyper-bola
Cone Index	38	22.3	6.73	5.82	Hyper-bola

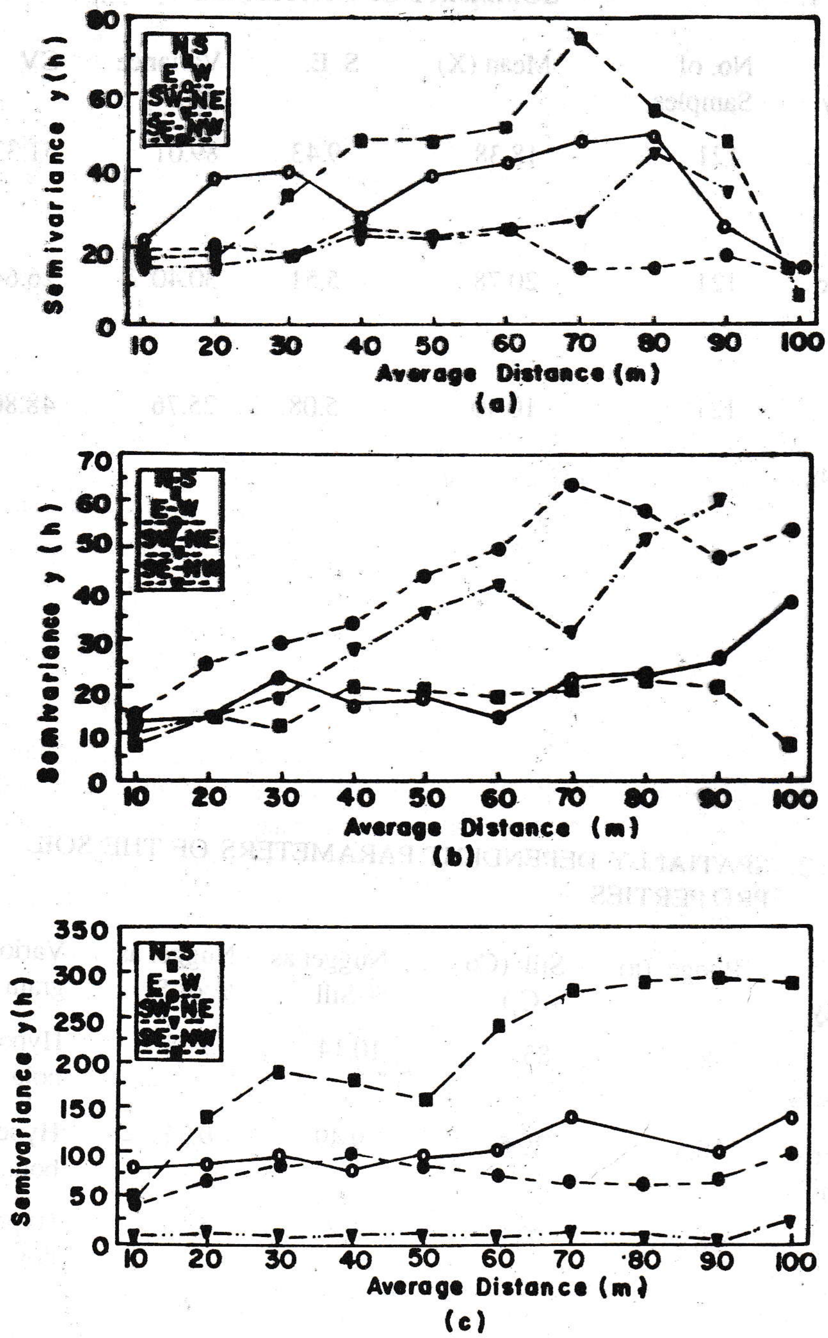

Fig. 1 : Variograms of soil Properties showing variations in different directions (a) % Gravel (b) Cone Index (CI) (c) Moisture Content (MC).

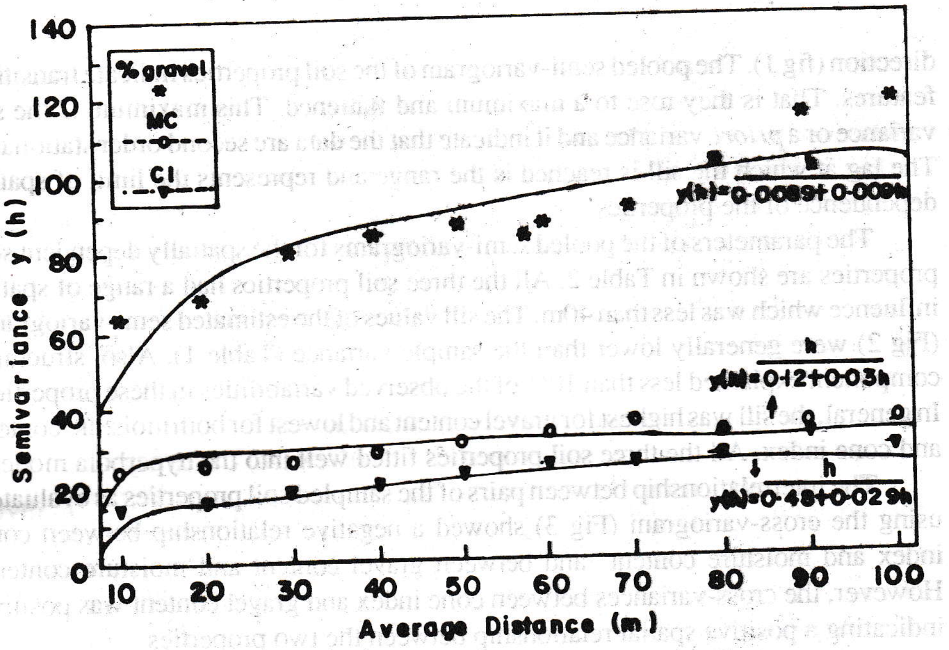

Fig. 2 : Pooled Variograms of Soil Properties

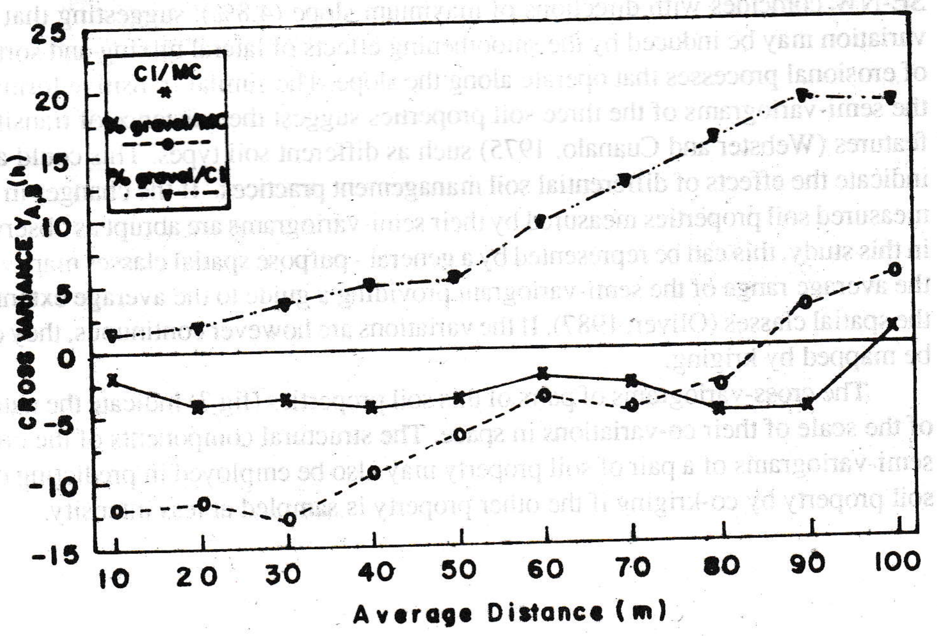

Fig. 3 : Cross - variograms of Pairs of Soil Properties .

direction (fig 1). The pooled semi-variogram of the soil properties indicate transitive features. That is they rose to a maximum and flattened. This maximum is the sill variance or a *priori* variance and it indicate that the data are second order stationary. The lag at which the sill is reached is the range and represents the limit of spatial dependence of the properties.

The parameters of the pooled semi-variograms for the spatially dependent soil properties are shown in Table 2. All the three soil properties had a range of spatial influence which was less than 40m. The sill values of the estimated semi-variograms (Fig 2) were generally lower than the sample variance (Table 1). Also, structural component explained less than 10% of the observed variabilities in these properties. In general, the sill was highest for gravel content and lowest for both moisture content and cone index. All the three soil properties fitted well into the hyperbola model.

The interrelationship between pairs of the sampled soil properties as evaluated using the cross-variogram (Fig 3) showed a negative relationship between cone index and moisture content and between gravel content and moisture content. However, the cross-variances between cone index and gravel content was positive indicating a positive spatial relationship between the two properties.

Discussions

The transitive form of the semi-variograms generally indicate that the data are second-order stationary. The direction of maximum variation of the soil properties SE-NW coincides with directions of maximum slope (4.8%), suggesting that the variation may be induced by the smoothening effects of lateral mixing and sorting of erosional processes that operate along the slope. The similar transitive forms of the semi-variograms of the three soil properties suggest the existence of transitive features (Webster and Cuanalo. 1975) such as different soil types. This could also indicate the effects of differential soil management practices. If the changes in the measured soil properties measured by their semi-variograms are abrupt as observed in this study, this can be represented by a general - purpose spatial classes map, with the average range of the semi-variogram providing a guide to the average extent of the spatial classes (Oliver, 1987). If the variations are however continuous, they can be mapped by kriging.

The cross-variograms of pairs of this soil properties (fig 3) indicate the nature of the scale of their co-variations in space. The structural components of the cross semi-variograms of a pair of soil property may also be employed in predicting one soil property by co-kriging if the other property is sampled at less intensity.

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