Spatial analysis as a reconnaissance survey technique: an example from acid sulphate soil regions of the Mekong Delta, Viet Nam

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1 Summary

In the Mekong Delta, Viet Nam, a study was carried out to determine the spatial variability of soil properties in acid sulfate areas, with the joint aims of selecting the most suitable soil properties for distinguishing between soil units and the best scales for soil survey. The method chosen used nested sampling and nested analysis of variance. Results showed, that in these acid sulfate soils, EC (and consequently soluble sulfate) was a useless attribute for distinguishing between soil units. Depth to jarosite was a reasonably reliable criterion for distinguishing between soil units at various scales in areas of acid sulfate soils having jarosite mottles in the profile, but short range variability of this property was also large. In areas having acid sulfate soils without jarosite mottles, the presence/absence of jarosite is a useful characteristic for mapping at semi-detailed and reconnaissance scales.

Résumé

Une étude permettant de déterminer la variabilité spatiale des sols sulfaté-acides, avec le but de choisir les propriétés des sols les plus appropriées pour séparer les unités des sols, ainsi que les échelles aux quelles ces propriétés varient, a été réalisée.

La ferme de Lang-Bien située dans la Plaine des joncs (avec des SSA sur matériau originel pauvre en matière organique, généralement oxydés jusqu'à une profondeur de plus d'un mètre) et la ferme 85B située dans la partie occidentale de la Plaine de Ha Tien (avec des SSA issus d'un matériau originel argilo-tourbeux, généralement oxydés sur moins d'un mètre de profondeur), ont été choisies comme superficies d'étude.

Pour séparer les unités des sols sulfaté-acides, les propriétés suivantes ont été enregistrées:

- altitude relative;
- utilisation des terres (1 = sans végétation; 2 = inondé; 3 = joncs; 4 = autre végétation naturelle; 5 = riz submergé; 6 = forêt);
- topographie (1 = plat; 2 = faiblement ondulé);
- classe de drainage (1 = très pauvre: plus de 6 mois d'inondation par année; 2 = pauvre: 3 à 6 mois; 3 = modére: < 3 mois; 4 = bon: pas d'inondation);

- matériau originel (1 = argile fluviatile; 2 = sable fluviatile; 3 = sédiment argileux d'eau saumâtre (vasière pyritique potentiellement acide);
- efflorescences de sels à la surface du sol (0 = non; 1 = oui);
- profondeur de la nappe d'eau en cm;
- profondeur de l'apparition du jarosite en cm;
- profondeur de l'apparition de la pyrite en cm;
- nomenclature des horizons conformément à la FAO;
- épaisseur de chaque horizon;
- classe d'argile en % (1 = 10%, 2 = 10-20%; 3 = 20-40%; 4 = > 40%);
- couleur d'après Munsell (teinte, valeur et chroma de la matrice de sol de chaque horizon);
- pH de la couche supérieure du sol;
- Ec de la surface du sol en extrait sol-eau 1:5;
- état de maturation de chaque horizon (1 = non maturé; 2 = demi-maturé; 3 = maturé, test au champ);
- présence de taches de jarosite dans chaque horizon (0 = néant; 1 = rares; 2 = frequentes; 3 = abondantes);
- présence de taches oranges ou bruns dans chaque horizon (rares, fréquentes, abondantes = comme pour le jarosite);
- présence de taches rouges dans chaque horizon (rares, fréquentes, abondantes = comme pour le jarosite);
- estimation au champ de la matière organique dans la partie supérieure du sol ainsi que dans le sous-sol réduit (1 = 0-10%; 2 = 10-20%; 3 = 20-30% et 4 = > 30% du volume).

Pour la détermination de l'échelle à la quelle ces propriétés varient, on a utilisé la technique d'échantillonnage en nids (Figure 3) et l'analyse de la variabilité des propriétés (Figures 5 et 6).

Les résultats montrent que dans les superficies à SSA, le EC (et par conséquence aussi le sulfate soluble) n'est pas un paramètre utile pour la séparation des unités des sols. Par contre, la profondeur de l'apparition du jarosite est un critère valable et stable durant de longues périodes (différemment du pH par exemple, qui varie beaucoup au cours des saisons). La profondeur de l'apparition du jarosite peut être utilisée pour la séparation des unités des sols à différentes échelles, dans les superficies à SSA à taches de jarosite, tout en tenant compte de la variation sur courte distance. Dans les superficies à SSA sans taches de jarosite, la présence/absence du jarosite est un critère utile pour la cartographie de reconnaisance ou à moyenne échelle.

2 Introduction

The aim of soil mapping is to discover and record the pattern of variation of soil within a given area. Because the kind of soil present at any given place on the earth's surface is strongly affected by its geology, landform, climate, hydrology and vegetation, these phenomena can give a good indication of the nature of the soil and how and where it changes. In many landscapes, the sampling density necessary to characterize the soil can be inferred from reconnaissance studies using stereo aerial photographs that allow the scale of the soil pattern to be deduced from the textures, three-dimensional views and the tones present on the imagery. It is well known that both aerial photo interpretation and 'free' ground soil survey are most effective when the soil pattern is strongly related to the patterns of landform, vegetation and hydrology. These conditions prevail in terrain with a clear relief, and in situations where the natural patterns of drainage and vegetation have been little disturbed.

There are many situations, however, particularly in plain lands, or in areas that have been cleared of the natural vegetation, where the soil pattern cannot easily be interpreted from the external expression of landscape differences. In these situations, aerial photo interpretation and other reconnaissance techniques are likely to be unsatisfactory for exploratory studies prior to detailed soil survey work.

In soil mapping using only field sampling, there is a direct relation between sample spacing, the size of the individual soil units that can be mapped, and the scale of the soil map used to display the results. By the sampling theorem (a rule of thumb from signal theory), it is impossible to recognise a pattern unit if it has been sampled only once; consequently an absolute minimum of two samples are needed to distinguish a pattern unit in one direction. By analogy, a minimum of four observations are needed to recognise a block of land belonging to a given kind of soil. Mapping conventions (see Vink 1961) relate sampling density to map scale through the number of samples or observations per cm of map. So, using a map of scale 1:10.000, four samples on a square grid would be able to resolve a minimum pattern unit of 1 ha; at a scale of 1:1.000.000 four samples would resolve a unit of 10 × 10 km.

Many soil survey organizations determine sample spacing from map scales, assuming a priori, that standard topographic map sheet scales will allow soil pattern to be resolved as far as required, with external evidence from landforms etc. being used to support regular sampling. In many cases there is no reason to expect that an a priori choice of map scale, and hence sampling interval, will be the most appropriate for any given area. In fact, in areas with large, simple soil patterns, this approach will result in a waste of survey effort. In complex, highly variable areas, the chosen sample spacing may be completely inadequate. So, in situations where the size of the soil patterns cannot be deduced from the external aspects of the landscape, or for soil properties having a distribution that is unlikely to be directly related to landform or vegetation, it is sensible to first undertake pre-survey reconnaissance studies in order to determine the size and complexity of the patterns to be mapped. These pre-survey studies should ensure that the most appropriate soil properties and sampling intervals are used for any given area, thus maximizing survey efficiency.

In 1982 the need for pre-survey reconnaissance studies arose in the context of a project of collaboration between the agricultural universities of Wageningen, the Netherlands and Can Tho, Vietnam.

The aim of this project was to carry out research for management of acid sulfate soils. One of the components of the research was to describe and map the occurrences of actual and potential acid sulfate soils in the Mekong delta. Because of the unavailability of aerial photographs it was not possible to undertake a reconnaissance study of the size of the patterns of soil variation prior to the field work. Also, in the field, a quick appraisal of the pattern size of soil variation was not possible because of a) the extent of the area to be covered, b) the almost total lack of perceptible relief, c) the removal of the original vegetation, now replaced by an obscuring reeds vegetation and d) the strong disturbance of the natural drainage pattern by an intricate system of man-made canals. Moreover, because the survey personnel had only a limited experience in the area and the total time available was only a few weeks, it was essential to find a reconnaissance technique that would allow a quick and effective appraisal of the scale of the soil variation.

The results of such a study, it was hoped, would permit subsequent soil survey activities to be better planned. To this end it was necessary to find out which soil properties would be most useful for mapping actual and potential acid sulfate soils, and to discover their spatial scales of variation. It was also necessary to find out if the same properties could be used over the other parts of the Mekong delta, where other surveys would be carried out later.

The problem was approached by using a technique of spatial analysis: nested sampling and nested analysis of variance. The nested method was used in two study areas. The aim of this paper is to describe how this method was used in the Mekong Delta, to present some of the results achieved, and to discuss the practical advantages and disadvantages of this technique in the context of a short-term study with limited budgets and manpower.

3 The study areas

3.1 Description of the Mekong Delta

The Mekong Delta, situated at the most southern tip of Vietnam between 9 and 11° N and 105 and 107° E. covers an area of roughly 4 million hectares. Except for a narrow strip in the border area with Kampuchea, where some old granite and limestone outcrops and Pleistocene Mekong river terraces are found, the entire delta is built up of Holocene fluviatile, brackish water and marine sediments.

The fluviatile sediments are found in the central part of the delta, along and in between the river streams. The marine sediments are found in a broad strip along the south-eastern coastline, and in a narrow strip along the north-western shore.

The brackish water sediments are found in the backswamps to the north-east and the west of the river streams. Here, during sedimentation, all conditions for the formation of acid sulfate soils were fulfilled (Van Breemen & Pons 1978); the presence of an iron containing sediment, sulfate-containing seawater, Fe and S reducing bacteria, a dense vegetation, tidal movement and slow sedimentation. Two large uninterrupted areas of actual acid sulfate soils can be distinguished. East of the river the Plain of Reeds, and in the north-west corner of the delta the Ha Tien Plain. The acid sulfate soils in the Plain of Reeds are generally derived from heavy clay sediments with a low organic matter content, and are mostly deeply oxidized; the pyritic subsoil occurs at a depth of 1.5 to 2 meters. In the Ha Tien Plain, especially in the western part, the acid sulfate soils are for the major part derived from peaty clay sediments with the pyritic subsoil at a depth roughly between 70 and 150 cm. Although these soils have most properties associated with acid sulfate soils, they usually do not show jarosite mottles. The morphology of these soils is discussed by van Mensvoort and Tri (1986).

In the southern part of the delta scattered low lying areas with actual and potential acid sulfate soils are found, mostly derived from clay sediments with low organic matter (Brinkman et al. 1986).

Extensive areas of potential acid sulfate soils have been found only in the most south-western tip of the delta, and in the delta of the Saigon river, south of Ho Chi Minh City. In both areas the formation of potential acid sulfate soils is still continuing.

3.2 Description of the two areas chosen for study

For our study, two areas were selected: I) Lang Bien Farm, situated in the Plain of Reeds (acid sulfate soils with parent material low in organic matter, generally oxidized to more than one meter depth), and II) Farm 85B, situated in the western part of the Ha Tien Plain (acid sulfate soils derived from peaty clay parent material generally oxidized to less than one meter depth).

The farms were chosen because they are situated in places considered to be representative for large areas of acid sulfate soils. Furthermore, the farms supplied transportation, lodging and labour for the survey teams.

The field work was carried out in the dry season. Lang Bien farm in March 1982 (4 days), 85B in March/April 1983 (one week).

3.2.1 Lang Bien farm

Lang Bien farm, covering 300 ha, is situated in the Plain of Reeds, about 20 km east of Sa Dec town in the Dong Thap Province (Figure 1).

The soils of the farm range from acid sulfate soils with the sulfuric horizon within 50 cm depth (Sulfaquepts) to acid sulfate soils with the sulfuric horizon at greater depth (sulfic and palesulfic Tropaquepts, Pons et al. 1986) and non acid soils (Tropaquepts). The farm is subjected to deep flooding (0.5 – 1.5 m) in the rainy season. Tidal movement is absent in the rainy season, and is only a few decimeters in the dry season. In the early part of the rainy season (April – May – June) water in the canals turns very acid as a result of acid being washed out from the dikes of recently dug canals. On the deeply developed acid sulfate soils and the non-acid soils the farm cultivates deep water rice. The area with Sulfaquepts is partly covered by Melaleuca leucadendron forest, partly covered with reeds (mainly Xiris indica, a short, unusable reed and in some places Cyperus spp and Eleocharis spp).

3.2.2 Farm 85B

Farm 85B is situated in the centre of the Ha Tien Plain (Figure 1), halfway along canal 8000, which connects the town of Tri Ton with the Rach Gia – Ha Tien Canal. The farm covers an area of 3800 ha, 1900 ha on either side of canal 8000. Besides a few creekbeds, which are filled with peat, the entire area consists of Sulfaquepts, dominated by acid sulfate soils that show no jarosite mottles in the oxidized horizons. The farm is subjected to a 0.5 – 0.8 m flood in the rainy season. In that season tidal movement is absent. In the dry season the difference between high tide and low tide is about 30 cm. In the 85B area many excavation works have been undertaken in recent years. Acidity washes from the dikes and raised beds in the early rainy season,

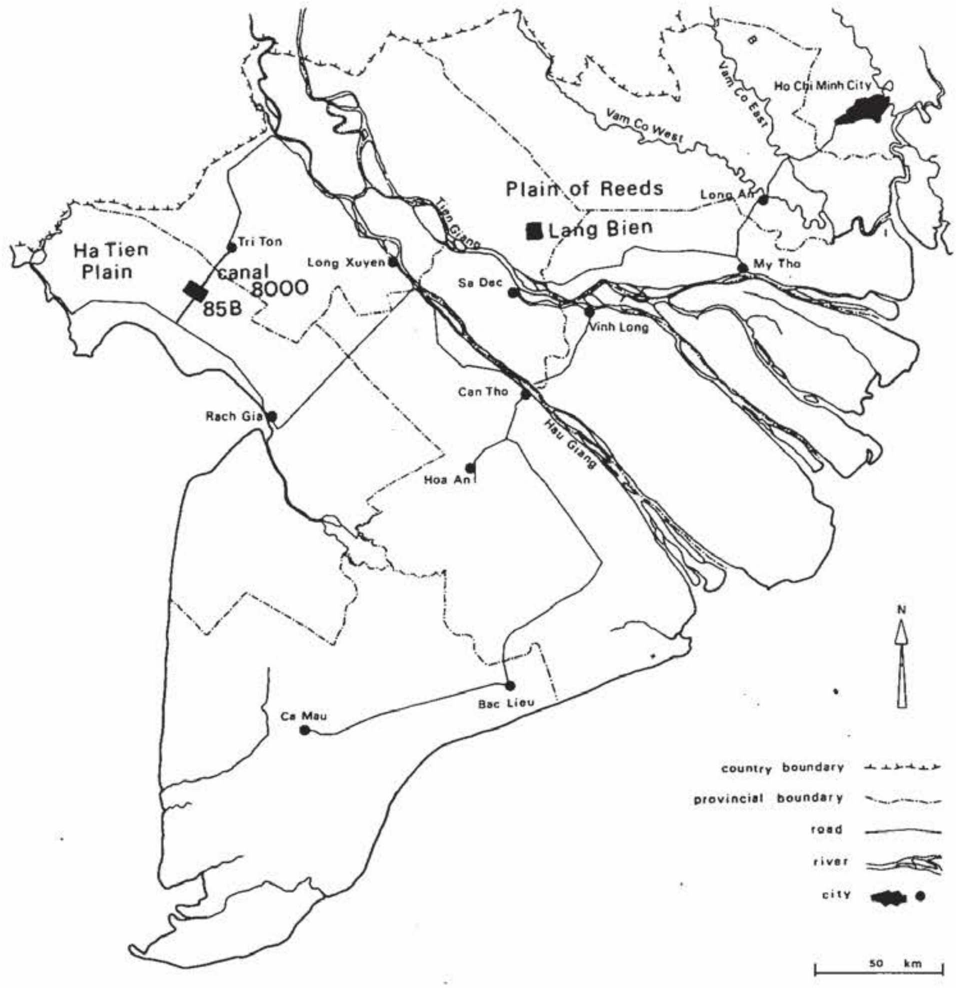

Figure 1 Location of the study areas Lang Bien and 85B

when surface water becomes extremely acid. 85B has tried to grow deep water rice on an area of 1500 ha with discouraging results. Rice performed better on acid sulfate soils with jarosite than on those without. Except for some 300 ha, which are still in use for deep water rice, most of the farmland is covered with reeds: Cyperus spp, Eleocharis spp, Scleria peaformis and Imperata cylindrica. Melaleuca leucadendron is destined to be the main crop, and has been planted on part of the land where deep water rice failed.

4 Methods and procedures

4.1 Soil properties recorded

The main aim of this study was to determine which soil properties were most suitable for distinguishing between different types of soil, and the scales at which these properties could best be mapped. The latter aspect determines the most efficient sampling spacing for mapping and the reliability of the soil maps.

Until recently, the most widely used method of distinguishing between different acid sulfate soils in Vietnam was based on measurement of pH and sulfate content of the surface soil (Moormann 1961; van Breemen and van Mensvoort 1982).

The following criteria were used:

	SO_4^{--}	pH
slightly acid	0.05 – 0.1%	> 4.2
moderately acid	0.1 – 0.15%	3.5 – 4.2
strongly acid	> 0.15%	< 3.5

In this study we recorded as wide a range of properties from soil augerings and simple field laboratory measurements (pH and EC) as was practically feasible.

In Lang Bien the following properties were observed:

- Relative altitiude compared to a chosen base level (m);
- Land use (1 = bare, 2 = inundated, 3 = reeds, 4 = other natural vegetation, 5 = floating rices, 6 = forest);
- Topography (1 = flat, 2 = slightly undulating);
- Drainage class (1 = very poor: inundation > 6 months per year; 2 = poor: 3 – 6 months; 3 = moderate: < 3 months; 4 = good: no inundation);
- Parent material (1 = river clay, 2 = river sand, 3 = clayey brackish water sediment (potentially acid, pyritic mud);
- Salt efflorescence on the soil surface 0 = no; 1 = yes;
- Ground water level in cm below surface;
- Depth to jarosite in cm below surface;
- Depth to pyrite in cm below surface.
- Horizon nomenclature according to FAO;
- Begin and end depth of each horizon;
- % clay class (1 = < 10%; 2 = 10-20%; 3 = 20-40%; 4 = > 40%); Munsell hue, value and chroma of the soil matrix in each horizon;
- Field pH of the surface soil;
- EC of the surface soil in a 1:5 soil: water extract;
- Ripening stage of each horizon (1 = unripe, 2 = halfripe, 3 = ripe, field test by squeezing);
- Presence of jarosite mottles in each horizon (0 = none, 1 = few, 2 = common, 3 = many);
- Presence of orange or brown mottles in each horizon (few, common or many as with jarosite);
- Presence of red mottles in each horizon (few, common or many as with jarosite);
- Field estimate of % organic matter in the surface soil and in the reduced subsoil (1 = 0-10%; 2 = 10-20%; 3 = 20-30% and 4 = > 30% by volume);

The same properties were observed in the 85B region with the following exception:

air dry pH of the surface soil was determined as well as field pH.

4.2 The nested sampling technique and analysis of variance

4.2.1 The theory and method of nested sampling

In order to determine the most efficient sampling interval for soil mapping, it is necessary to know the sizes of the patterns of soil variation. In the absence of clear external information (from landform, vegetation, etc.), these scales can be estimated using the technique of nested sampling (Webster 1977, Nortcliff 1978).

In conventional soil survey, the landscape is divided into mapping units. In terms of the analysis of variance, this means that the variation of the soil in the landscape is partitioned into variation between, and variation within classes. No account is taken of the spatial extents of the mapping units. The model used is:

$$Z(x) = \mu + \alpha_i + E \qquad (1)$$

where Z(x) is the value of soil property Z at location x in class i, μ is the general mean of the property over study area, α_i is the difference between the mean of class i and μ, and E is a random variable, with mean 0 and variance δ^2.

When an area that has been mapped at a reconnaissance scale is remapped at a detailed scale, the original mapping units are often redivided. The subdivision is based on soil taxonomy (e.g. series within families) so that with every successive division there is a nested set of soil classes within larger classes and so on. The one-way analysis of variance can easily be extended to this hierarchical situation so that it is possible to estimate the amount of variation associated with each level in the classification hierarchy.

A corollary to refining the classification with increasing map scale, is that sampling intervals decrease, so smaller areas of land are delineated (Burrough 1983). The analysis of variance can then be used to indicate the improvement in map quality brought about by increasing the mapping scale (Beckett and Burrough 1971).

The analysis of variance technique can be used to estimate how map quality varies with sampling spacing as follows. Sample observations are arranged in clusters over several well defined sampling distances. The analysis of variance is used to estimate the amount of variation that occurs over each sampling distance. A plot of cumulative variance against sampling distance will then yield information about the average sizes of the soil patterns. For example, in Figure 2, property A shows little increase in variance up to a sampling distance of 20 m. Thereafter, the variance increases rapidly. The conclusion to be drawn is that property A varies little within 20m and to sample at a spacing closer than 20m reveals nothing extra. Property B shows similar behaviour over the range 2-20m, though the residual variation is much greater. Almost all the variation of B occurs within 200 m.

Consequently attempting to map B using a sample spacing of greater than 200m would be a waste of effort; the interpretation is that B has a pattern of variation that can best be mapped by an observation net having a spacing between 20 and 200 m. Property C has most of its variation present at the shortest sampling distance. The interpretation is that the variation of C occurs over such short distances that it cannot be mapped.

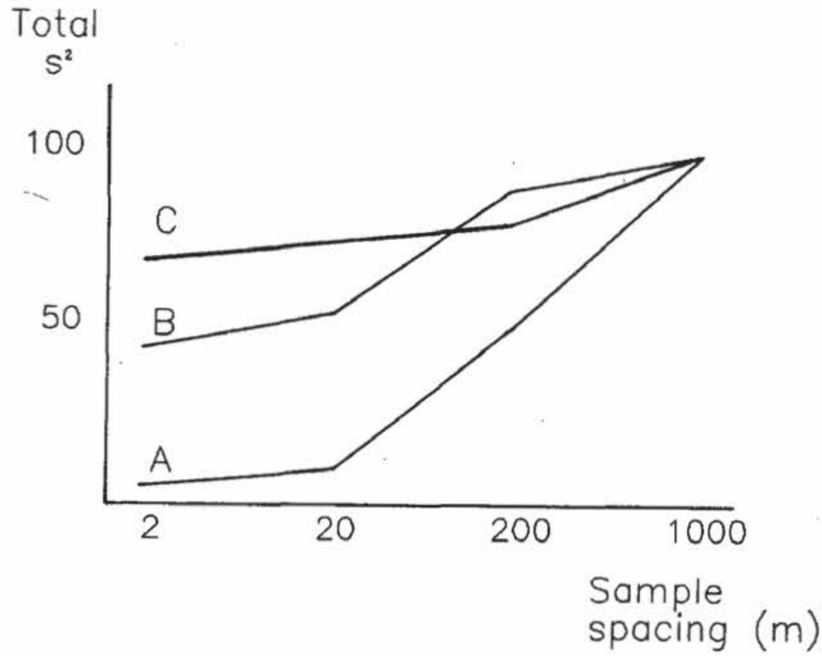

Figure 2 Examples of 3 variograms: cumulative variance (%) against sample spacing

4.2.2 The procedure for nested sampling

The procedure for nested sampling is as follows. Before fieldwork, the area to be surveyed is covered by a grid of squares, the actual dimensions of which reflect the size of the area.

A number of these squares are chosen at random, subject to the condition that the average distance between squares corresponds to the largest sampling distance thought to be worthwile. These squares are then further subdivided into sub-squares (usually by a 5 × 5 square grid) and a set of sub-squares is chosen as before. The centre of each sub-square serves as the reference point for a set of observations located at random orientations but at nested sampling distances (example: Figure 3). The resulting sampling scheme has the structure shown in Figure 4. In the field, it is only necessary to locate the centre of each sub-square, the actual sampling points can be determined by pacing along previously determined, random directions, indicated by a compass.

If g is the number of levels in the hierarchy, and n_g is the number of subdivisions at each stage, the components of variance at each stage δ_g^2 can be estimated as shown in table 1.

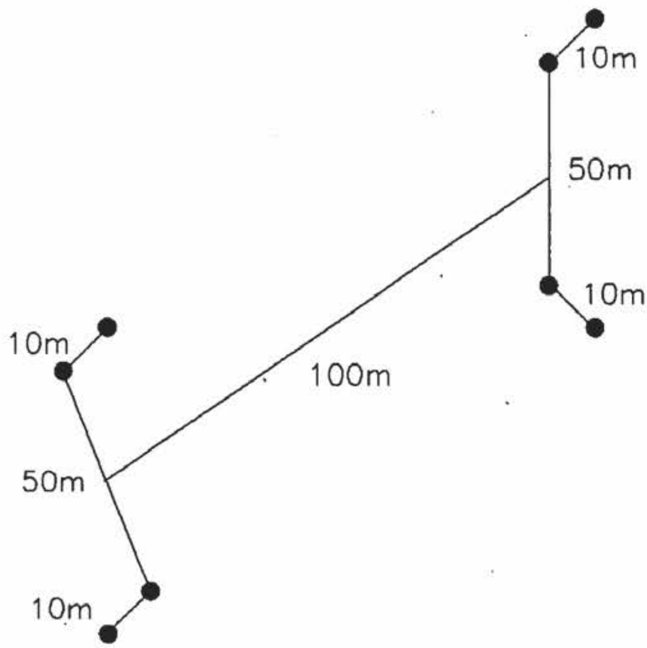

Figure 3 Examples of 8 soil observations at nested sampling distances 10m, 50m, 100m

4.3 Nested sampling in practise

4.3.1 Lang Bien area

From a 1:10.000 field map the farm was divided into squares each 1000 × 1000 m; four of these were chosen with centres at a distance of 2000 m. Each of these squares was then divided into 25 sub-squares, each 200 × 200 m; two sub-squares were chosen at random, subject to the condition that their centres were 500 m apart. This resulted in 8 points on the map, each the centre of 8 soil borings; these were located along random orientations in pairs at 10, 50 and 100m apart. An example of such a cluster of 8 borings is shown in Figure 3.

Sixty-four borings were carried out, and the results were entered on a field sheet, an example of which is given in Table 2. The 64 points were located accurately by a land survey team. The soil surveyors followed to carry out the borings and observations.

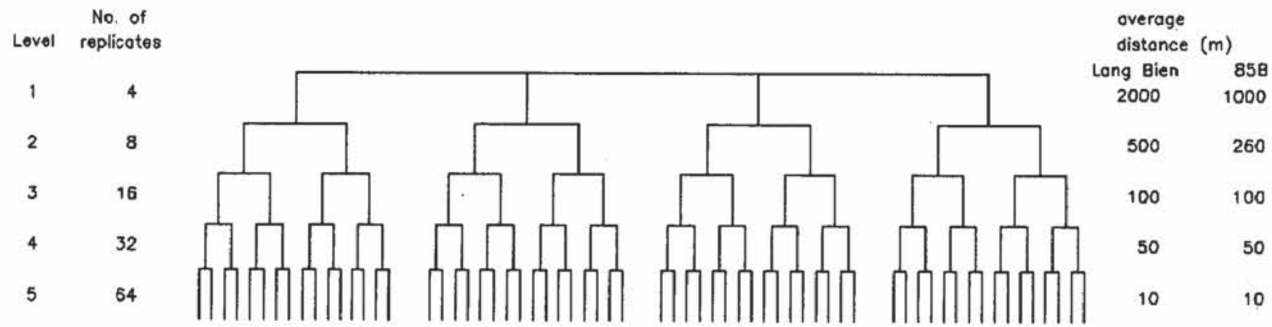

Figure 4 Structure of the sampling scheme for 64 soil observations

Table 1 Analysis of variance for hierarchial classification with five levels (stages)

Source	Degrees of freedom	Sums of squares	Estimated components in mean squares
Stage 1	f_1-1	$\sum_{i=1}^{f_1} m_i(\bar{x}_i-\bar{x})^2$	$U_{11}\sigma_1^2 + U_{12}\sigma_2^2 + U_{13}\sigma_3^2 + U_{14}\sigma_4^2 + \sigma_5^2$
Stage 2	f_2-f_1	$\sum_{i=1}^{f_1} \sum_{j=1}^{n_i} m_{ij}(\bar{x}_{ij}-\bar{x}_i)^2$	$U_{22}\sigma_2^2 + U_{23}\sigma_3^2 + U_{24}\sigma_4^2 + \sigma_5^2$
Stage 3	f_3-f_2	$\sum_{i=1}^{f_1} \sum_{j=1}^{n_i} \sum_{k=1}^{n_{ij}} m_{ijk}(\bar{x}_{ijk}-\bar{x}_{ij})^2$	$U_{33}\sigma_3^2 + U_{34}\sigma_4^2 + \sigma_5^2$
Stage 4	f_4-f_3	$\sum_{i=1}^{f_1} \sum_{j=1}^{n_i} \sum_{k=1}^{n_{ij}} \sum_{l=1}^{n_{ijk}} m_{ijkl}(\bar{x}_{ijkl}-\bar{x}_{ijk})^2$	$U_{44}\sigma_4^2 + \sigma_5^2$
Stage 5	η-f_4	$\sum_{i=1}^{f_1} \sum_{j=1}^{n_i} \sum_{k=1}^{n_{ij}} \sum_{l=1}^{n_{ijk}} \sum_{m=1}^{n_{ijkl}} m_{ijklm}(\bar{x}_{ijklm}-\bar{x}_{ijkl})^2$	σ_5^2
Total	n-1	$\sum_{i=1}^{n_i} \sum_{j=1}^{n_j} \sum_{k=1}^{n_k} \sum_{l=1}^{n_l} \sum_{m=1}^{n_m} (\bar{x}_{ijklm}-x)^2$	

f_g is the number of classes at the stage
n_i, n_{ij}, are the numbers of classes at the 2nd, 3rd stage
m_i, m_{ij}, are the numbers of observation in the ith, ijth, class at the 1st, 2nd, stages

Table 2 Example of a completed field sheet from Lang Bien area

Profile number	Date	Surv. name	Grid ref.	Alti- tude	Land use	Topo- graph.	Drain. class.	Parent mat.	Salt efflor.	Groundw.- table	cm to jarosite	cm to pyrite	Perdysic horizon	Class. code	EC topsoil
X 10	11/3/82			1.241	4.2	0	1	3	1	82	60	110		tSuTp	0.725

Horizon	Begin depth	End depth	% clay	Hue	Value	Chroma	pH field	pH airdry	Ripening	Mottles jarosite	Brown mottles	Red mottles	Organic matter
Ah	0	8	4				4.0	3.7	3	0	0	0	2
Bg1	8	40	4						3	0	1	0	0
Bg2	40	60	4						3	0	1	0	0
Bgj3	60	110	4						2	1	1	0	0
Cr	110	200	4	5Y	4	1			2	0	0	0	0

4.3.2 85B area

From a 1:10.000 field map, 8 adjacent (4 × 2) squares of 1000 × 1000 m were chosen. As in Lang Bien each of these squares was divided into 25 sub-squares of 200 × 200 m; two were chosen at random with midpoints at 250m distance. Each midpoint was, again, the centre of a cluster of 8 borings in pairs at 10, 50 and 100 m.
A total of 128 borings was carried out. By choosing 8 adjacent blocks,the statistical analysis could be carried out for 3 adjacent areas, each comprising 4 squares, 8 sub-squares and 64 borings. These areas will be called 1, 1/2 and 2 from now on.

5 Results and discussion

5.1 Correlations between properties

Tabulated summaries of the results for Lang Bien and 85B are given in table 3 and table 4, respectively.

As can be seen from the field sheet (Table 2) all properties have been recorded as numbers on ratio scale. These data were analysed using correlation matrices and nested analysis of variance.

Correlation analysis showed that there were few large correlations between soil properties in the two areas. The large correlations found are rather obvious: depth to the C horizon and depth to pyrite have a correlation coefficient of 0.815 in Lang Bien and 0.861 in 85B area. Moderate correlation coefficients (0.5 – 0.7) were found between some properties in Lang Bien: e.g. relative altitude and groundwater table, depth to jarosite and groundwater table, depth to pyrite and groundwater table, depth to pyrite and depth to jarosite, depth to jarosite and depth to the C horizon. These high correlations are not very surprising, all these properties are relief-associated.

5.2 Variance of properties

The nested analysis of variance for all properties in Lang Bien is presented in Figures 5a, 5b and 5c and for some properties in 85B in figure 6a to 6f. The cumulative percentage of variance at each sampling level has been plotted against sample spacing. The complexity of the figures reflects the presence of several overlapping scales of variation in the soil pattern. The following interpretations can be made:

5.2.1 In Lang Bien

The short-range variance of EC (74% at 10 m distance) is so large that for all practical purposes it is a useless attribute for distinguishing between soil units at any scale.

The large percentage short-range variance of most properties of the C horizon (Hue, Value, texture, ripening stage, organic matter content) reflects the spatial uniformity of the subsoil in the area. The variance of texture of the C horizon only changes between 50 and 100 m, which suggests that variation of soil texture is caused by infilling

Table 3 Summary of Lang Bien properties

Property	Mean	Minimum	Maximum	Nr misses	Cv%
Altitude (m)	1.33	1.05	1.74	0	13.83
Groundwater (cm)	62	17	130	1	33.96
Depth jar. (cm)	66	24	145	12	34.59
Depth pyr. (cm)	106	67	169	12	22.41
Thickness A (cm)	19	6	50	0	56.22
pH field	4.4	3.3	6	1	13.18
EC mS/cm	0.54	0.1	1.05	9	42.59
Depth C (cm)	123	60	181	0	19.17
Value C	4.7	3	6	1	14.52
Chroma C	1	0	2	1	58.2

Land use : Reeds 39.1%; other natural vagetation 10.9%; floating rice 29.7%; floating rice mixed with other natural vegetation 17.2%; Melaleuca 3.1%
Drainage : Very poor 9.4%; poor 82.8%; moderate 7.8%
Salt efflorescence: 23% of observations with salt efflorescence on the surface
Org. matter : 0-10% Org. matter: 25%; 10-20% Org. matter: 75%
Texture C : Class 1: 3.1%; class 2: 0%; class 3: 7.8%; class 4: 89.1%
Hue C : 5YR: 1.6%; 5YR: 4.8%; 10YR: 12.7%; 5Y: 52.4%; N: 23.8%; 5GY: 1.6%; 5bg/3.2%
Org. matter C : 0-10% Org. matter: 85.7%; 10-20% Org. matter: 12.7%; 20-30% Org. matter: 1.6%
Ripening C : Unripe: 42.2%; halfripe: 50.8%; ripe: 7.9%

Table 4 Summary of 85B properties

Property	Mean	Minimum	Maximum	Nr misses	Cv%
Altitude (m)	0.54	0.13	0.99	0	39.08
Groundwater (cm)	137	89	187	27	15.34
Depth jar. (cm)	55	20	95	53	33.55
Depth pyr. (cm)	76	10	112	2	23.44
EC mS/cm	0.44	0.1	1.6	7	60.49
Thickness A (cm)	17	5	46	2	44.93
pH field A	3.4	2.5	4.4	9	10
ph airdry A	3.4	2.7	4.9	6	9.55
Value C	4.5	2	6	2	16.91
Chroma C	1.3	0	4	2	43.41
Depth C	84	10	133	2	25.48

Topography : Slightly undulating: 9%; flat plain: 91%
Drainage : 100% flooded 3-6 months per year
Brown mottles A : None: 11%; few: 64%; common: 25%
Ripening C : Ripe: 3%; halfripe: 86%; unripe: 11%
Org. matter C : 0-10% Org. matter: 39%; 10-20% Org. matter: 52%; 20-30% Org. matter: 86%; > 30% Org. matter: 2%
Org. Mottles C1 : None: 19%; few: 56%; common: 25%
Org. Mottles Ctotal : None: 15%; few: 57%; common: 28%
Hue C : 5YR: 2%; 7.5YR: 4%; 10YR: 49%; 2.5Y: 2%; 2.5Y: 2%; N: 1%; 5GY: 2%

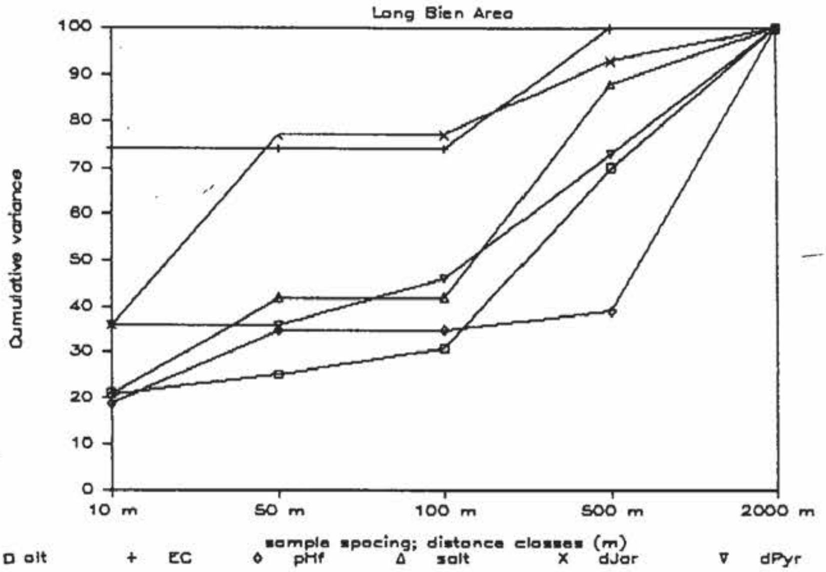

Figure 5a Variogram of 6 properties

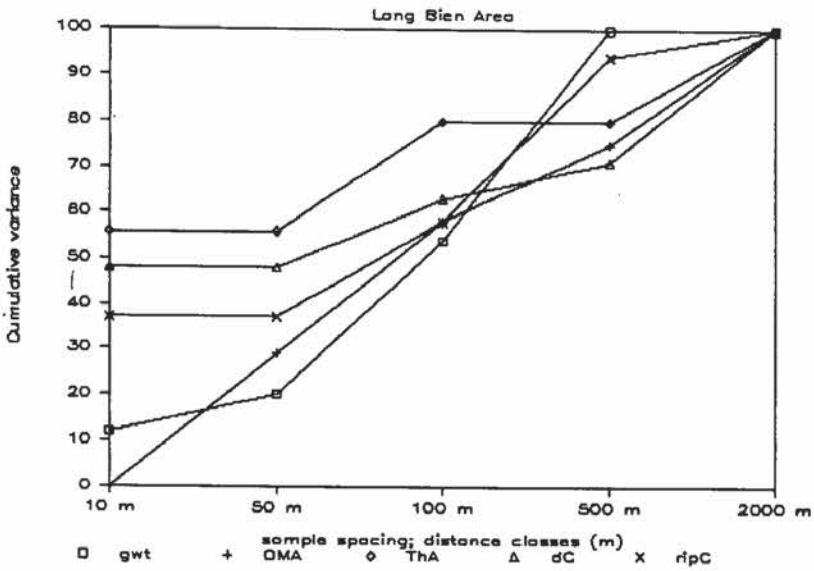

Figure 5b Variogram of 5 properties

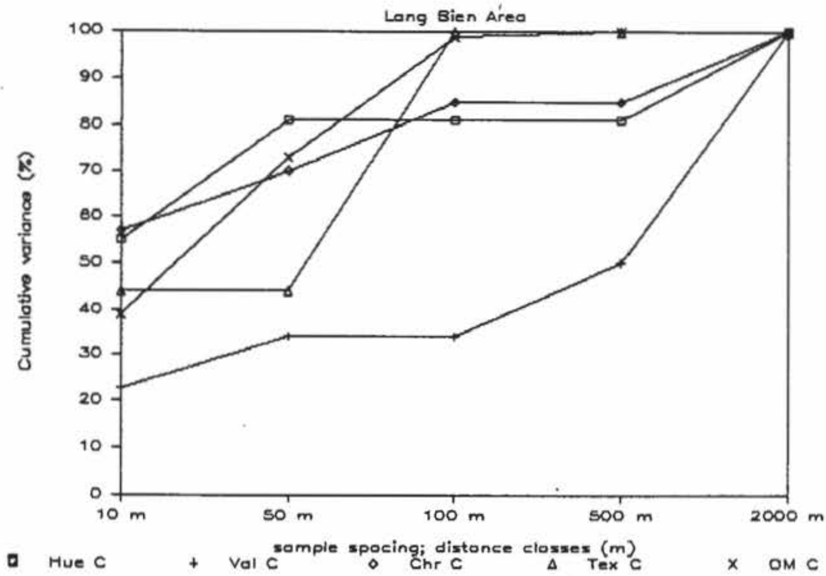

Figure 5c Variogram of 5 properties

of small gullies with lighter textured material in a predominantly heavy clay area.

The variation in the thickness of the A horizon, with a jump between 50 and 100 m may be attributed to land use (ploughing).

The variance of depth to jarosite (an important characteristic in distinguishing types of acid sulfate soils according to Soil Taxonomy) has jumps between 10 m and 50 m, and between 100 m and 500 m. So this property can be mapped by surveys at various scales with sampling distances somewhere between 100 and 500 m (leading to maps of scales 1:20,000 to 1:100,000). To reduce the confusion caused by the short range variance, for mapping it would be advisable to use average values from multiple observations within a small area (bulked samples) rather than single borings.

Properties with clear jumps in the variance occurring at distances between 500 and 2000 m can best be used for mapping at small scales, for example field pH.

5.2.2 85B

In 85B most properties have a large percentage short-range variance (variance within 10 m), and reach more than 70% of the total cumulative variance within 100 m. This reflects the general uniformity of the soil properties in the area: exceptions are elevation (see Figure 6a) and topography.

Depth to jarosite (see Figure 6b) also shows a large shortrange variance,and a general upward trend without jumps, making this property of little use for distinguishing soil units in the 85B area. A complicating factor is that in many cases no jarosite is found in the area. The original nested analysis of variance regards such observations as missing values, assuming that jarosite is present in every boring. Of the 64 borings in each of the three areas the number of missing values was 31, 22 and 36 respectively. Because these were too large to be ignored, the nested analysis of variance was applied to data indicating the presence and absence of jarosite (see Figure 6d). The outcome was very surprising: about half the variance was reached within 50 m, but between 50 and 280 m, for two out of three areas, no further rise occurred, and a large rise was found between 280 and 1000 m.

This indicates that, in this area, the presence or absence of jarosite is a useful characteristic for surveys at mapping scales varying between 1:56.000 and 1:200.000.

Relative altitude shows a similar large jump between 280 and 1000 m, but unfortunately correlation analysis shows that this property bears no relation to any of the other properties thought important for mapping acid sulfate soils.

6 Conclusions

a. How useful is a reconnaissance study of spatial variability? In a very limited amount of time (for Lang Bien four, for 85B six days) a large number of data were collected from which the sizes of the main scales of the soil patterns were found. This was important for choosing the scale at which a reliable soil map could be made. The study also quickly indicated the most suitable attributes that could be used for distinguishing between soil units. This is important information in an area such as the Mekong delta, where only a limited amount of surveys have been executed.
b. The Lang Bien study showed the uselessness of EC for distinguishing between soil units. It should be remembered, that outside the zone with sea water intrusion, EC has a direct relationship to the sulfate content in soil moisture.
c. Depth to jarosite, which is a stable characteristic of acid sulfate soils (contrary to pH for example, which changes with every season), is a reasonably reliable criterion for surveys at various scales. Short range variation should be suppressed by using average values from multiple augerings within small areas (bulk sampling).
d. Properties associated with relief (elevation, depth to jarosite, depth to pyrite, ground water table, depth to the C horizon, drainage class) show a reasonable degree of correlation in the Lang Bien area.
e. In areas such as 85B, where acid sulfate soils with and without jarosite occur, the presence or absence of jarosite is a reliable characteristic for distinguishing mapping units at scales between 1:50.000 and 1:200.000. Field information indicated that soils with jarosite have a somewhat higher agricultural potential, emphasizing the importance of this characteristic.

References

Beckett, P.H.T., and P.A. Burrough 1971. The relation between cost and utility in soil survey IV. J. Soil Science 22: 466-480.

Brinkman, R., Nguyen Bao Ve, Tran Kim Tinh, Do Phuoc Hau, and M.E.F. van Mensvoort 1986. Acid sulfate materials in the Western Mekong Delta, This syposium.

Burrough, P.A. 1983. Multiscale sources of spatial variation in soil. I. The application of fractal concepts to nested levels of soil variation. J. Soil Sci. 34: 577-597.

Moormann, F.R. 1986. The soils of the republic of Viet Nam. Ministery of Agriculture, Saigon.

Nortcliff, S. 1978. Soil variability and reconnaissance soil mapping: a statistical study in Norfolk. J. Soil Sci. 29: 403-418.

Pons, L.J., M.E.F. van Mensvoort, and Le Quang Tri 1986. A proposal for the classification of Vietnamese acid sulfate soils according to Soil Taxonomy. This symposium.

Van Breemen, N., and M.E.F. van Mensvoort 1982. Report of a mission to Viet Nam, VH 10 project mission report 5, Dept. Soil Sci. & Geology, Agric. University Wageningen.

Van Breemen, N., and L.J. Pons 1978. Acid sulfate soils and rice. Soils and Rice, IRRI, Los Baños, Philippines, pp 739-762.

Van Mensvoort, M.E.F., and le Quang Tri 1986. Morphology and genesis of actual acid sulfate soils without jarosite in the Mekong Delta, Viet Nam. This symposium.

Vink, A.P.A. 1963. Planning of soil surveys in land development. Publication International Institute for Land Reclamation and Improvement (ILRI) no 10.

Webster, R. 1977. Quantitative and numerical methods in soil classification and survey. O.U.P. 269 pp.

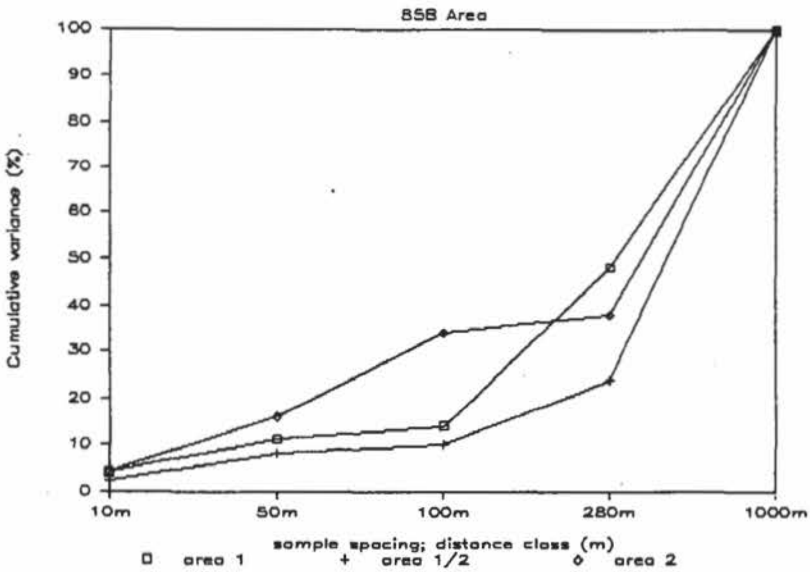

Figure 6a Variogram of altitude

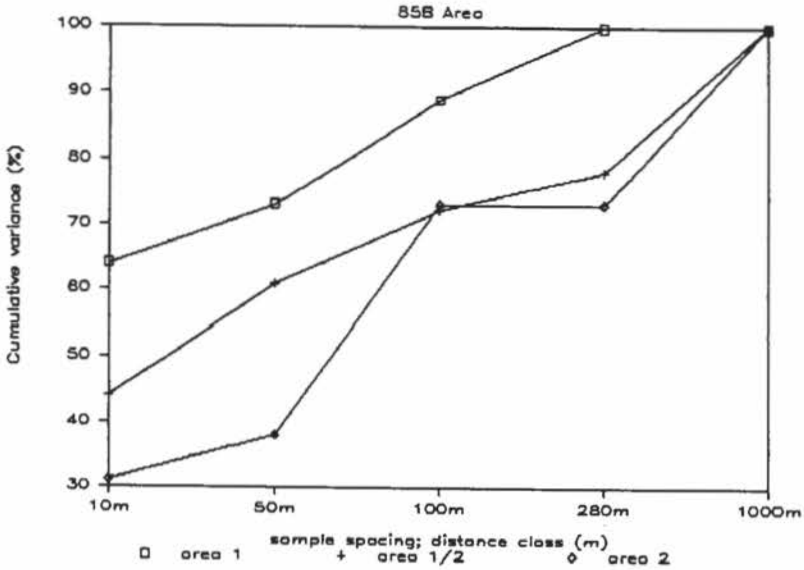

Figure 6b Variogram of depth to jarosite

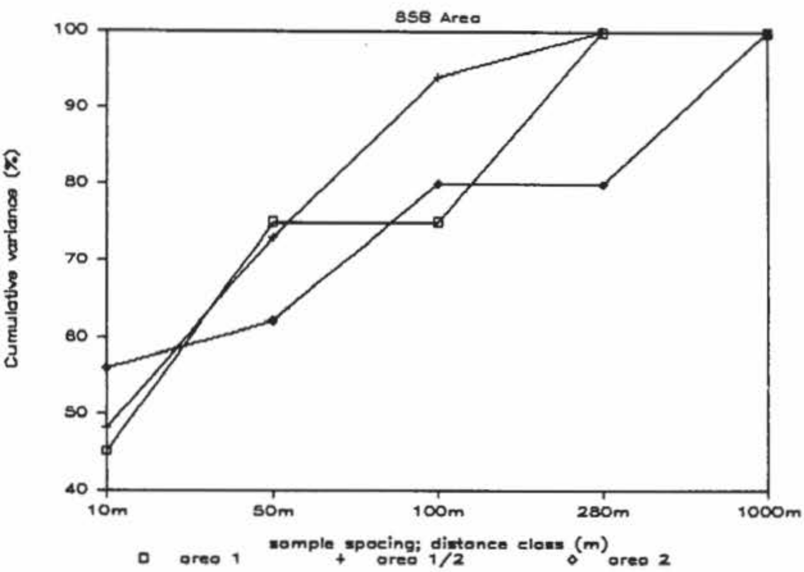

Figure 6c Variogram of org.matter C-hor.