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# Water and nutrient fluxes as indicators for the stability of different land use systems on the Terra firme near Manaus

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# 10) Variability of soil physical parameters in agroforestry research

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Soil spatial variability has been recognized and documented at different scales (Beckett and Webster, 1971; Jury et al., 1991;Warrick, 1998). Many soil physical properties vary with transient soil features and some are not normally distributed and time and spatial dependent.

Agroforestry research has to cope with the soil variability, because the experiments are normally carried out at large treatment plots, with an inherent spatial variability between plots, while measurements among system components within the plots, may be spatially dependent. These inherent soil variability if not take in account may obscured treatment effects or lead to misinterpretations of results.

We will emphasize in this review concepts to accommodate spatial variability of soil physical parameters in order to build predictive models at field scale of flow and transport problems, and sampling procedures to allow comparisons of soil physical properties among treatments.

### *Sources and structure of soil variability*

The sources of soil spatial variability have been grouped in two broad categories, systematic and random. The natural systematic variability is a gradual or marked change in the soil properties as a function of their genetic development.

Systematic variability caused by variation of parental material and intensity of soil forming factors such as chronosequence, toposequence, climasequence, biosequence, landforms such as mountains, plateaus, basins, valleys, and geomorphic elements such as summit, shoulder and backslope, can be observed even at relatively short distances.

The heterogeneity of many soils presently reflects variations of the Holocene climate as well as cryoturbate features of Pleistocene glacial – interglacial periods of the Quaternary (Kutílek and Nielsen, 1994).

Systematic variability is simultaneously and concurrently, superposed by changes in soil properties that varies randomly and as consequence its measurements. It becomes extremely complex and difficult to interpret for predictive use (Youngs, 1983).

**Random variations, also called stochastic variations, are also caused by natural processes like soil formation factors, parent material, biological activity and changes that result from human management activities, such as agricultural activities like clearing, ploughing, subsoiling, irrigation and drainage.**

The placement or imperfect broadcasting of fertilizer or dung, row cultivation, and the growth of row or tree crops, all has a tendency to superimpose additional heterogeneity in the soil properties. In agrosilvopastoral system the intense grazing frequently produce dung or urine patches.

**In some tropical areas biogenetic factors seem to be a dominant source of soil surface variability. Mound building by termites and ants, and worm cast, produce heterogeneity faster than it can be smoothed out by diffusion and mixing (Moormann and Kang, 1978). The termites mound alteration in soil physical and chemical properties are persistent and are reflected in variable growth of crops even when mounds are flattened for mechanized agriculture (Moormann and Kang, 1978).**

Oilpalms form a common element in the secondary regrowth of shifting cultivated land in the moister parts of West Africa. It is commonly found in sites where were old palm plantations that the soil surface bulk density lowering with distance from the trunk of former palms until 2 m to 3 m. Similarly, organic carbon content is consistently higher, not only in the surface but also in the subsuperficial horizon. Consequently most sites near to the former palm trunk exhibit better soil conditions than the adjacent site soil (Kang, 1977).

In shifting cultivation agriculture, the preclearing vegetation or cultivation during the previous year, influences strongly the performance of annual crops in Africa (Kang and Moormann, 1977). Higher soil variability of abandoned pastures in relation to primary forest has also been found in Amazon basin (Correa and Richard, 1989).

Soil alterations by clearance of the Amazonian forest were evaluated in relation to pore size distribution. Results indicated a significant reduction of the water available as a consequence of mechanical action in the clearance and posterior management practices (Grimaldi et al., 1993; Teixeira et al., 1996a).

Patterns on throughfall and stemflow in multi-strata agroforestry lead to a mosaic of situation with respect to quantity of water inputs into the soil (Schroth, et al.1999), hence creating spatial soil water patterns.

**Representative elementary volume (REV) or Representative elementary area (REA)**

A practical definition of a representative elementary volume (REV) or representative elementary area (REA) is the smallest volume or area of soil that contains a representation of microscopic variations in all the forms and proportions present in the system (Bear, 1988). Hence it does not only depend on the physical parameter investigated but also variability of the soil under study. Moreover, values of a REV of the same property for different soils are not identical (Warrick, 1998).

In soil physics, the soil sample generally involves a volume or area of soil to be measured resulting in a continuous real number. Therefore, statistical properties such as mean and variance of a physical property of a soil cannot be predicted correctly without estimating the representative elementary volume (REV) or representative elementary area (REA) (Iwata et al., 1995).

Sample sizes smaller than the REV may not yield a reliable estimate of the average property and are often characterized by a large variability (Hendrickx et al., 1994; Rice and Bowman, 1988). It should be stressed that this is not primarily a statistical problem but has a physical significance. Sample sizes larger than the REV do not yield additional information and do not further reduce the variability of the measurement.

The procedure usually adopted to estimate REV of a physical soil property is to measure samples with different sizes; the smallest sample size whose means and medians show stable values can be chosen as the REV. In practice, sample size is determined not only by the magnitude of the variance, but also to provide an operational convenience in a measurement method (Iwata, 1995; Miyazaki, 1993).

## Sampling techniques

No attempt will be made herein to review details of statistic sampling procedures. They are mainly presented to encourage agroforestry researchers to consider the value of these techniques for future sampling schemes to evaluate soil physical properties. Detailed discussion about sampling scheme are found in Webster and Oliver (1990), Snedecor and Cochran (1989), Kempthorne and Allmaras (1986),and Cochran (1977).

An understanding of the true definitions about accuracy, precision and bias is important to select methods of measurements and to avoid some impediments in the subsequent statistical analysis.

The accuracy of a measurement refers to the correctness in estimates the true value, whereas precision is a measure of the deviation of results from the mean value, hence high precision demonstrates only the reproducibility of the analysis, and it does not necessary imply accuracy of the results.

Precision can be greatly increase with enhance of the number of replications (Tan, 1996; Kempthorne and Allmaras, 1986). Whether precision or accuracy is more important depends on the specific situation being investigated, although both properties are obviously desired for reliable data.

Bias refers to systematic difference between the statistical mean and the true value (Kempthorne and Allmaras, 1986). Bias can be minimized by use of standardized materials, correct data acquisition and calibration procedures. Bias associated with installation and maintenance of access tube in soil moisture measurements with neutron probes are discussed by Willians and Sinclair (1981) and in TDR technique by Teixeira et al. (1999) and Weitz et al. (1997).

The number of observations needed to characterize a soil properties in a certain sampling unit is determined by the variance of the property, the confidence level chosen, and the tolerance deviation about the mean, which is acceptable by the objectives of the investigation.

If an estimate of the variance from the property desired to be evaluated is available, then an assessment of the number of samples necessary in the next sampling, to obtain a given precision with a specified probability may be obtained using Equation 1 (Petersen and Calvin, 1986; Snedecor and Cochran, 1989).

$$n = \frac{Z_{\alpha}^{2} s^{2}}{D^{2}} \qquad \text{[Equation 1]}$$

Where Z is the standardized normal variance at level of probability ?; $s^2$ is the variance and D is the tolerance or specified acceptable error. Values assumed by Z are presented in some statistical books (Steel et al., 1997; Snedecor and Cochran, 1989).

To exemplify the use of this procedure, suppose that the estimate of the mean value of bulk density determined in a previous studies was 1500 kg $m^{-3}$ and the its variance 200 kg $m^{-3}$. The calculated number of sample (n) necessary to estimate the bulk density with a 95% of confidence with a tolerance of 10% of deviation of mean value is seven samples.

$$n = \frac{(1{,}96)^2(200)^2}{(150)^2} = 6{,}8 \approx 7$$

While adoption of high confidence level in statistical approaches is common found in some studies of soil properties, in many soil physical properties, we must frequently accept either a lower confidence level or higher confidence interval to maintain a sampling scheme within feasibility.

The coefficients of variations of many soil physical properties are shown by Wilding (1985), Jury et al. (1991), and Warrick, (1998). However the value presented by these authors is only guidance. It is always better to determine previously or to recover a formerly studies in the same area to achieve more confident values about the variance.

The use of Equation 1 implicates to assume that the population has a Gaussian or normal distribution and, the measured values are independent. The violation of the first assumption is not very serious if the number of samples is large enough that we can invoke the central limit theorem.

Failure of the normal approximation occurs mostly when the population contains some extreme individuals that dominate the sample average causing an asymmetric skew (Beckett and Webster, 1971). Standard procedures for ascertaining the type of probability distribution function (pdf) are Shapiro-Wilk's W test; Kolmogorov-Smirnov test for 2 samples (Steel et al., 1997; Parkin and Robison, 1989) or graphical methods like the fractale diagrams (Jury et al., 1990).

The probability distributions of statistical parametric test are in most of the cases, based on the assumption of normal distribution of the data. However, parameters like saturated and unsaturated hydraulic conductivity have been showing frequently log-normal distributions (Lauren et al., 1988; Nielsen et al., 1973). The transformation of lognormal data can lead to normalization. In practice a variable is considered to be lognormal distributed if the logarithm of the variable is normally distributed.

Identification of extraneous values and recommended rules for designating them are discussed by Dixon et al. (1986). Discrepant datum with strongly disparity from the bulk of the measurement, normally caused by sampling fault, untypical soils conditions etc., should be identified and eliminated.

In many experiments is useless to attempt control or to compare determined parameters to such a degree unless sufficient replications are used for detection of hypothesized treatment effects. The required replication needed to detect with determined accuracy to achieve a least significant difference can be calculated using the Equation 2 (Teixeira et al., 1996b; John et al., 1981; Cassel and Bauer, 1975).

$$n = \frac{Z_\alpha^2 s^2}{(LSD)^2} \qquad \text{[Equation 2]}$$

Where n is the number of replication; LSD is the least square difference and Z, ? and s are the same parameters defined in Equation 1.

We exemplify the use of equation 2 with a followed hypothetical situation. In a research program about soil water the standard deviation of soil moisture content was estimated to be of 0.10 $m^3$ $m^{-3}$ within the plots replications measurements. In this conditions, to detected a significant difference with at $p<0.05$ of 0.05; 0.10 and 0.20 $m^3$ $m^{-3}$ among treatments, the number of replications calculated with Equation 2 are respectively 31, 7 and 2 samples per treatment.

A practical inference about this statistical approach is that if the sampling scheme has a reduced number of replications and/or the soil property has a high variance, only greater differences among treatments can be detected in spite of true treatment effects could be happening.

Sampling repeatedly in time should be composed by several dispersed samples, and the exact location of each sampling point should be marked permanently. At the next sampling period, sample should be collected as close as possible to the original points, thus holding effects of spatial variability to a minimum (Sisson and Wierenga, 1981).

***Subsampling***

In many types of soil investigation, the use of subsampling or multistage sampling is advantageous. Whit this technique, the sampling unit is divided into a number of smaller elements and only parties of these units, so-called subunits, are sampled.

The primary advantage of subsampling is that it permits the estimation of some characteristics of the larger sampling unit without the necessity of measuring the entire unit (Petersen and Calvin, 1986). At each stage of sampling, an additional component of variation, the variation among smaller elements within the larger units, is added to the sampling error (Petersen and Calvin, 1986, Cochran, 1977). Therefore, subsampling will usually decrease the precision with which the soil property is estimated.

The sampling scheme could be designed more efficient, and therefore less costly, by using an adequate combination of the number of sampling and subsampling units, that provide the maximum precision at a given cost or that provides a specified precision at the lowest cost.

The statistical procedures to estimate the optimum subsampling rate are presented by Cochran, (1977) and Petersen and Calvin, (1986).

Santos and Vasconcelos (1987) and Ike and Clutter (1968) showed practical uses of subsampling technique to evaluate soil properties.

### *Composite sampling*

When only the average value of a soil property is needed, a substantial saving in sampling and analytical costs can be realized by composting samples. Bulking of equal amounts of individual samples reduces analytical effort and can provide a site mean, but gives no information on the variability within the site (Ball and Willians, 1968).

A number of field samples representing the soil population under study are thoroughly mixed to form a composite which is then subsampled for submission to the laboratory. Composite sampling plan should only be used for properties which are unaffected by physical disturbance, like particle-size, particle density, specific surface and gravimetric soil water content.

The number of samples needed to estimate the mean of the composite depends on the variability of the property and the desirable level of confidence (Petersen and Calvin, 1986; Ball and Willians, 1967).

### Independence of samples

Effects of agroforestry research on soil physical parameters are often existent, and experienced researchers and farmers are convinced of them, but statistical verification of these differences sometimes failed, most of times due to the spatial dependence among the samples.

Frequently soil properties measured at nearby locations vary less than those measured further apart, indicating that the samples may be not independent of each other.

The distances between two sampling sites at which respective samples are judged to be independent has to be determined. This distance, called "the range of influence", characterizes the spatial variability of the soil. With geostatiscal concepts it is possible to validate the basic assumptions of independence or to take into account the possible autocorrelation between measurements in estimating the variance of the mean (Vauclin et al., 1984).

The violation of independence of the sample may be a serious limitation to sampling schemes in agroforestry system. When the objective is to compare differences among system components, hence the samples are taken within the plot (i.e. to determine single tree effect) the samples may be not independent.

Gajem et al. (1981) studied the spatial dependence of 12 soil properties measured along different transects found these soil properties were correlated with each other over a distance that varied from a few centimeters to several meters.

Russo and Bresler (1981) determined that soil hydraulic properties were correlated over distances as follows; 21 m for saturated hydraulic conductivity, 55m for saturated soil water content, 25 m for residual water content and 35m for sorptivity.

Campbel (1978) found ranges of 30 m and 40 m for the sand content of two different soil types and Vieira et al. (1981) found the steady-state infiltration rates of Yolo loam soil to be spatially dependent with a 50-m range.

The spatial dependence and may also be a function of time (Sadding et al., 1985) and, most studies of the spatial variability of the physical properties of soils have been done on bare soil, in agroforestry research, the presence of plant cans modifies the structure of the spatial dependency.

Geoestatistical methods have been show to be able to reduce the sampling effort by using the variance in the neighborhood of each observation (Vieira, 1981; McBratney and Webster, 1983).

In agroforestry research, not infrequently, the vast sampling network of soil water studies that needed more at one day to read, cause error due to changes in time. In this situations networks should be arranged in blocks or series of replicates such that all treatments with the blocks were sampled before moving onto the next replicate. This procedure may permit that the effects of time will be balanced across all treatments and partially removed form the analysis of variance (John et al., 1981).

Other alternative to reduce the likelihood to obtain incomplete and useless data set, is the selection of only some few representative locations in the whole network to collect data. This technique is related with the concept of temporal stability, where some locations conserve the property to represent the mean and extreme values of the field water content or water potential at any time along the year (Gonçalves et al, 1999; Vachaud et al., 1985).

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