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"Soil Mechanical Analysis through Gamma Ray Attenuation"

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Soil Mechanical Analysis through Gamma Ray Attenuation

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Summary

A new soil mechanical analysis method based on the attenuation of a gamma-ray beam by a soil suspension under sedimentation is presented. The soil is initially dispersed by a classical method using 100 g of soil and 50 cm^3 of 1N NaOH brought up to a total volume of 1 litre with distilled water. The method utilizes a 300 mCi ^{241}Am gamma-ray source and a gamma spectrometer with a NaI($T\ell$) scintillation detector. Tests were performed with three distinct soils. Two red podsols and one dark red latosol, from Santa Barbara d'Oeste County, State of São Paulo, Brazil. The results obtained for sand, silt and clay fractions compared favorably with those of the classical pipette method with a linear correlation r of 0.96. The new method presents several advantages: no perturbation of the sedimentation process, direct observation of all particle fractions, and continuous analysis of particle size distribution.

1 Introduction

Soil, formed through the long term action of climate, organisms and other weathering processes on primary rock materials, is composed of particles having a wide range in size and composition. In order to understand the dynamic processes that occur in the resulting porous material it is fundamental to know details of the particle size distribution, which defines soil texture. Texture is one of the most important physical properties of soils. It is used extensively in relation to relevant dynamic processes such as erosion, water retention and movement, solute and plant nutrient mobility, soil strength, etc.

Dispersion of soil aggregates is classically done physically and chemically. The physical procedure consists of breaking down aggregates through mechanical forces while the chemical procedure involves the oxidation of organic materials and the dispersion of particles. These well established procedures (e.g., Gee & Bauder 1986) are not discussed here. The pipette method is the most widely used to measure the percentage of each particle fraction (Gee & Bauder 1986). It involves the extraction of a small volume of suspension with the aid of a pipette, at a fixed depth for different sedimentation times. This method is simple and easily performed but not completely free of errors. The main sources of error are

1. the differences in rate of sample col-

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lection with the pipette,

2. the depth of sample collection and
3. the perturbation of the sedimentation process by the pipette itself.

The method presented here minimizes these erros and allows a continuous observation of particle sizes without interfering with the sedimentation process.

2 Methods and materials

The method is based on the attenuation of a gramma-ray beam by the soil suspension under sedimentation. The intensivity of the gamma beam passing through the suspension at a given depth is related to the concentration of the suspension as it varies with time. From the attenuation of the beam intensity it is possible to calculate particle fractions. The attenuation equation for a gamma-ray beam passing through the sedimentation system composed of an acrylic plastic container, soil particles, water and sodium hydroxide (shown in fig. 1) can be written as:

$$I = I_o exp(\overline{\mu}_w X_p - \overline{\mu}_p D_p X_p) \qquad (1)$$

where I_o is the attenuated radiation beam (cps) from the system without the soil, I the attenuated radiation beam (cps) from the system with soil under sedimentation, $\overline{\mu}_w$ and $\overline{\mu}_p$ ($cm^2 \cdot g^{-1}$) the mass attenuation coefficients for water and soil, respectively; X_p (cm) the absorption thickness due to soil particles; and D_p ($g \cdot cm^{-3}$) the particle density. Equation (1) neglects the absorption thickness of sodium hydroxide, assumes the density of water is $1\ g \cdot cm^{-3}$ and assumes all particles have the same density (composition).

Relating the suspension concentration C ($g \cdot \ell^{-1}$) to the particle density and to the container internal thickness X (cm), we have:

$$X_p = \frac{C \cdot X}{D_p} 10^{-3} \qquad (2)$$

Substituting (2) into (1) we obtain:

$$C = \frac{\ell n(I_o/I)}{X(\overline{\mu}_p - \overline{\mu}_w/D_p)} \qquad (3)$$

From the measurement of I as a function of the sedimentation time at a choosen depth h (equivalent to the pipette depth) the suspension concentration is obtained using equation (3). Knowing the initial suspension concentration, the percentage of each particle size fraction can be calculated. Since measurements of I are performed in definite time interval ($\Delta t = 3$ seconds in our case), it is difficult to measure the initial concentration (corresponding to the start of the sedimentation process $t = 0$) through beam attenuation. Therefore, the initial concentration was calculated from soil mass and solution volume.

Three soils, two red podsols (PV_1 and PV_2) and one dark red latosol (LRd), were used to evaluate the new method. The soils were dispersed using NaOH as a dispersing agent (Gee & Bauder 1986).

A radioactive source ^{241}Am of 300 mCi was used to produce the gamma-ray beam, using the energy peak of 59.6 KeV. The detection system consisted of a NaI(Tℓ) crystal scintillator, photomultiplier cell, high voltage source, amplifier, monochannel discriminator and a counter/timer. The beam collimator on source side was rectangular (2×5 mm) and on the detector side was circular (12 mm diameter). Fig. 1 shows schematically the experimental arrangement. Several parameters were measured independently: water and soil

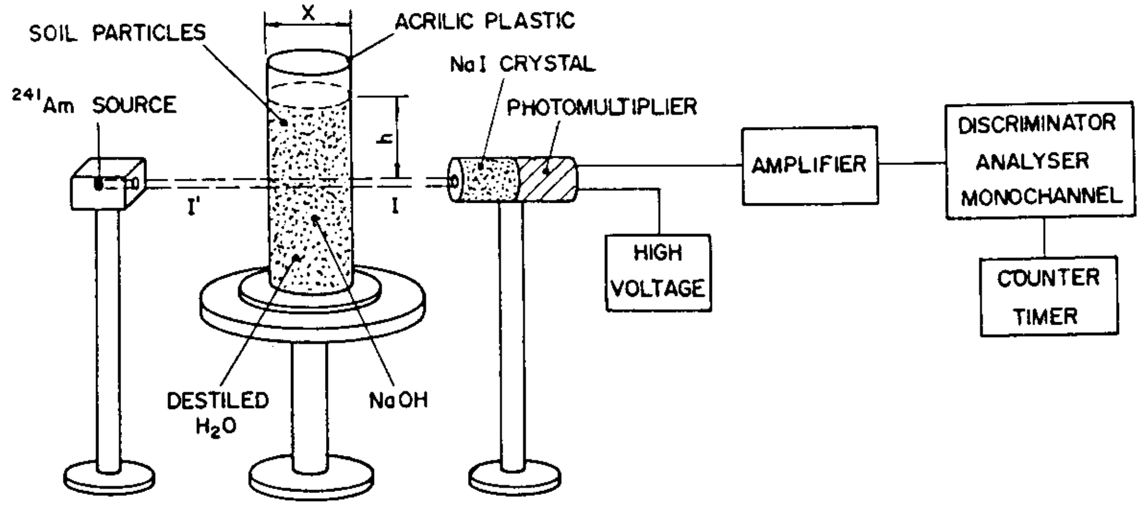

Fig. 1: *Scheme of the attenuation system.*

mass attenuation coefficients $\overline{\mu}_w$ and $\overline{\mu}_p$ for 59.6 KeV gamma-rays; internal thickness of the container X; suspension temperature T; depth h and the intensity of the gamma beam I_o leaving the container without soil particles.

3 Results and discussion

Tab. 1 presents some values of the previously measured parameters necessary for the calculation involved in equation (3). Fig. 2 shows the concentration changes at depth h, as a function of $\ell n(t)$ for each of the three soils. Concentrations calculated according to equation (3), using data of tab. 1 and I as a function of time, are presented cumulatively. Fig. 2 also shows the limits for the different particle size fractions according to the USDA classification. For the case of sand, silt and clay, tab. 2 and fig. 3 compare the results obtained by the new method and the pipette method. The linear regression coefficient r of these data is 0.96.

The functions generated on fig. 2 represent the cumulative suspension concentration as a function of the natural logarithm of time, which, when divided into selected intervals, permits the detailed study of the particle size distribution, as shown in figures 4, 5 and 6. Data shown in fig. 2 are carried out in such a way that each point for the new method represents the average of ten measurements while that for the pipette method stems from only one measurement.

The pipette method estimates sand content indirectly, using a sieve (no. 270) of 0,053 mm diameter openings. For the new method all fractions are measured during sedimentation, with the possibility of increasing the number of sub-divisions for both the sand and silt fractions.

4 Conclusions

Although the number of soils used to test the new method is relatively small, the very high regression coefficient of fig. 3 confirms the high potential of the method for the mechanical analysis of soils. The method does not interfere in the sedimentation process, measures all particle size fractions, permits a greater

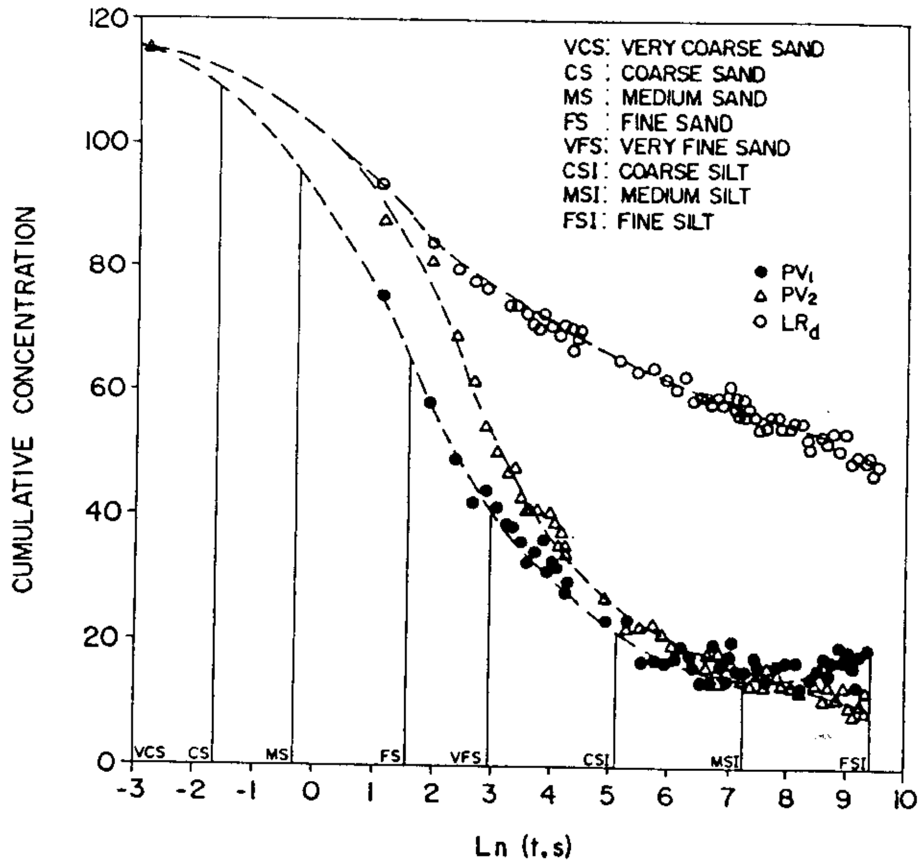

Fig. 2: *Cumulative soil particle concentration for red Podsols PV_1 and PV_2 and for dark red Latosol LRd as a function of the natural logarithm of time.*

soil	$\overline{\mu}_p$ (cm^2/g)	D_p (g/cm^3)	h (cm)	x (cm)	T (°C)	C_o (g/l)	I_o (cps)
PV_1	0.2652	2.68	4.75	5.95	23.5	115.5	27339
PV_2	0.2708	2.69	4.65	5.95	23.0	116.3	27121
LRd	0.3776	2.95	4.75	5.95	24.0	115.5	27662

Tab. 1: *Parameters measured for the three soils used in calculations.*

soil	sand %		silt %		clay %	
	gamma	pipette	gamma	pipette	gamma	pipette
PV_1	53.3	55	35.7	32	10.9	13
PV_2	63.9	63	22.4	18	13.9	19
LRd	34.3	29	22.8	17	43.4	54

Tab. 2: *Results obtained by gamma and pipette methods for sand, silt and clay of the three soils studied.*

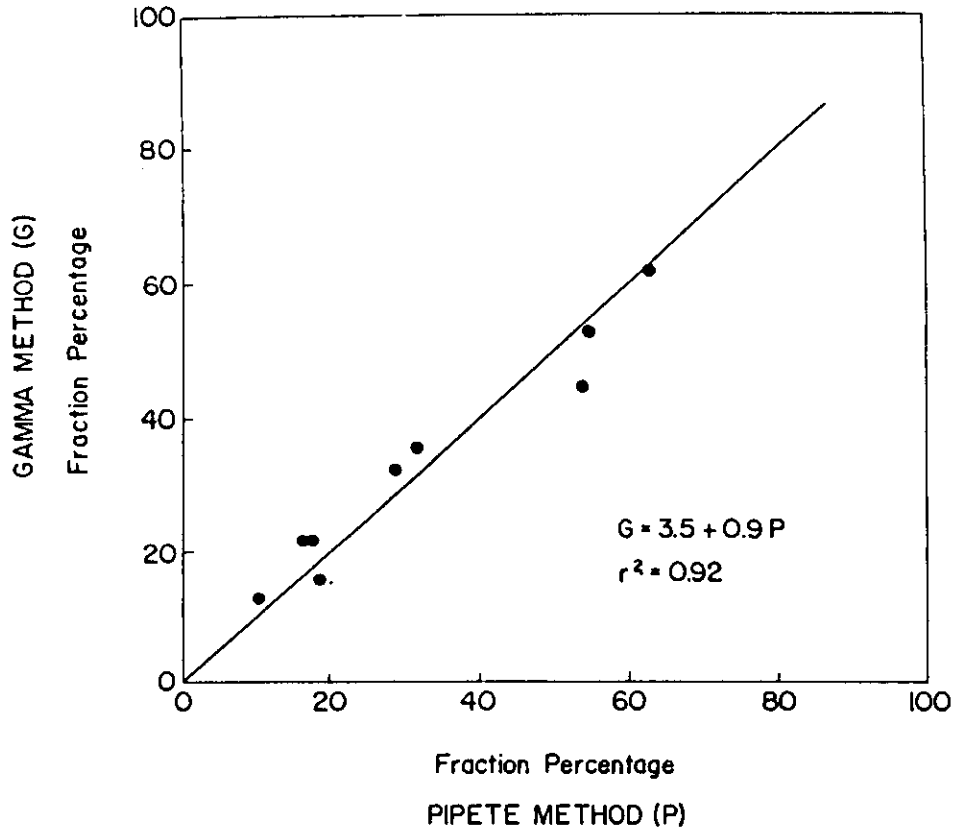

Fig. 3: *Comparison of sand, silt and clay data obtained by gamma and pipette methods.*

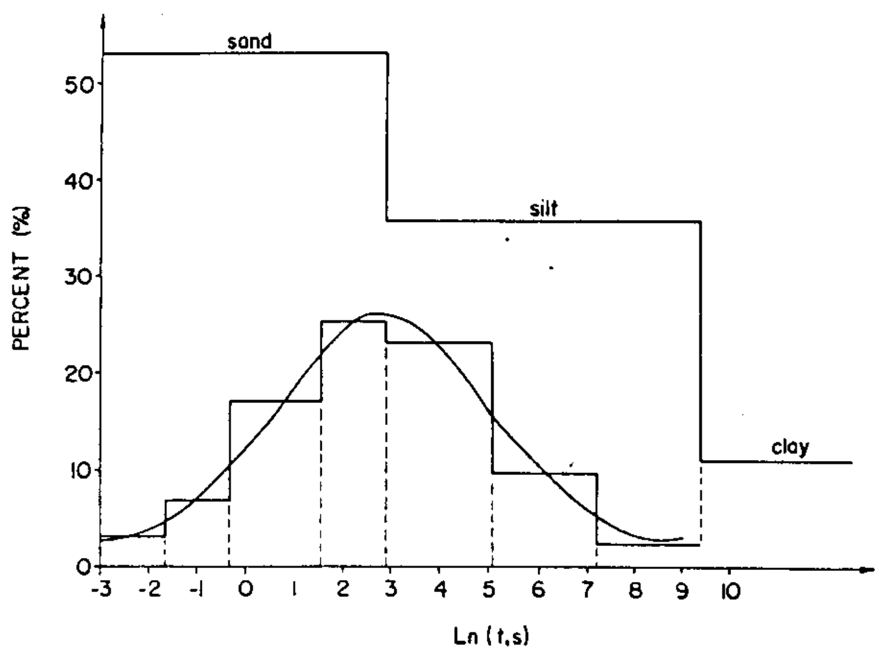

Fig. 4: *Detailed particle size distribution for red Podsol PV_1.*

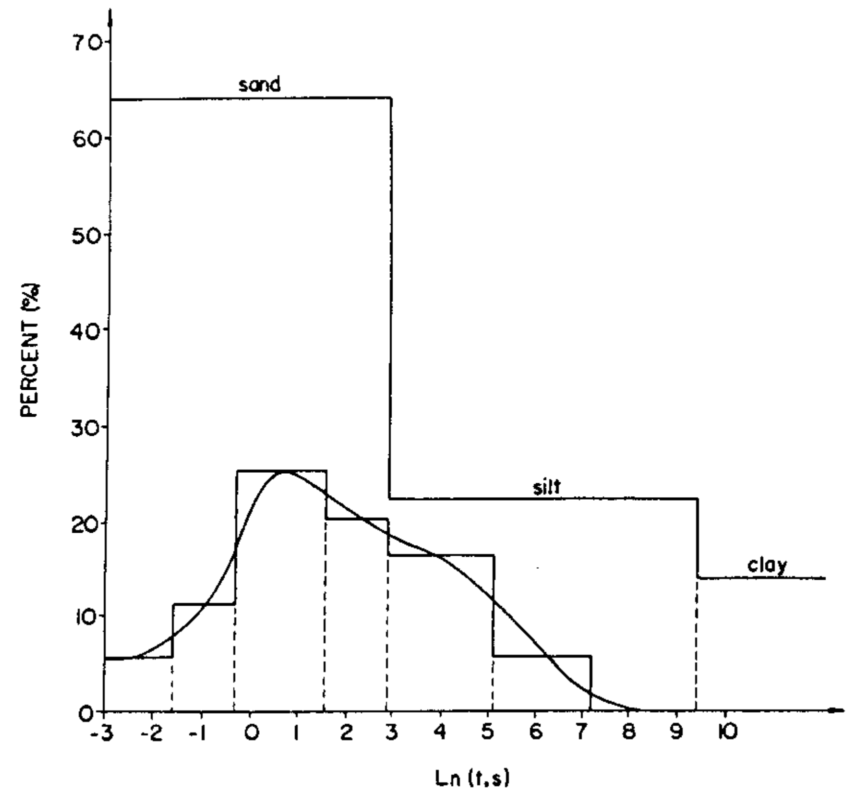

Fig. 5: *Detailed particle size distribution for red Podsol* PV_2.

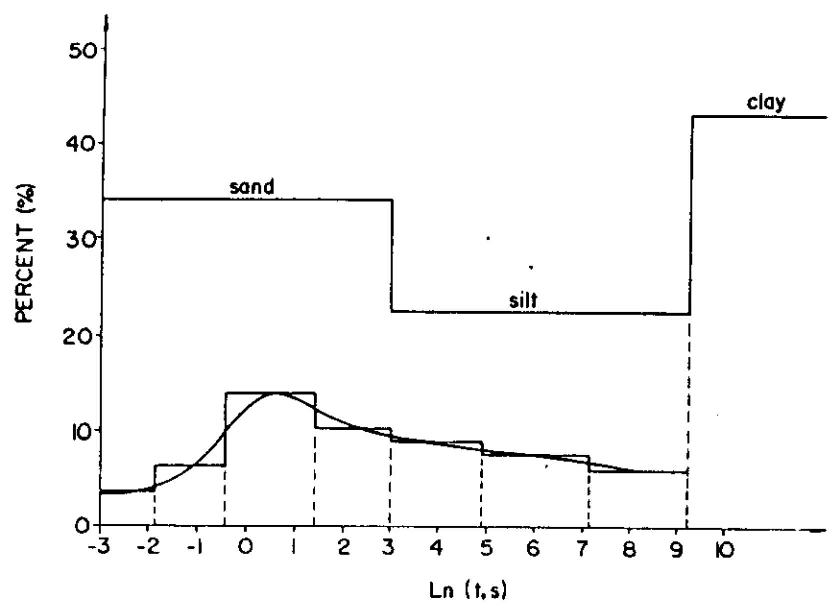

Fig. 6: *Detailed particle size distribution for dark red Latosol LRd.*

detail in the analysis of sand and silt fractions, and is convenient.

Asuming the same density for all soil particles is a restriction to calculate diameter distributions in both pipette and gamma-ray attenuation methods. In fact these methods measure soil particle velocity distributions. However the gamma method opens the possibility, using two distinct radiation energy beams, to calculate both the concentration and the density of all soil fractions simultaneously. Authors are now concerned with these measurements and also develop studies involving several sedimentation depths, optimization of beam count rates and collimation, measurement of initial concentration through gamma attenuation and system authomatization, in order to improve method's velocity, sensitivity and precision.

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