Automatic gamma-ray equipment for multiple soil physical properties measurements

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Introduction

Determination of soil physical parameters is sometimes very laborious and time consuming. For instance, the soil water retention curve takes several weeks. Particle density by picnometer and granulometry (texture) by pipette method are laborious methods. Other parameters as bulk density and total porosity are determined by gravimetric methods and depends on oven drying the samples for 24 hours.

In order to help in the soil physical parameters determination we have developed an automatic equipment based on the attenuation of a gamma-ray beam by soil samples. Two types of samples are analyzed: solid (undisturbed) and dispersed soil particles in water, allowing the measurement and estimation of the following parameters:

- Particle size distribution (measured);
- Retention curve (estimated by Arya and Paris (1981) method);
- Particle density (estimated by the measured mass attenuation coefficient of the soil sample);
- Bulk density (measured);
- Total porosity (estimated);
- Water content (measured).

The talk will focus on the explanation of gamma-ray attenuation method to measure and estimate the soil physical parameters mentioned above. Each method will be presented in details and calibrations and practical applications will be presented, as summarized bellow.

Material and Methods

Automatic gamma-ray attenuation equipment

Figure 1. Equipment for multiple soil physical parameters determination.

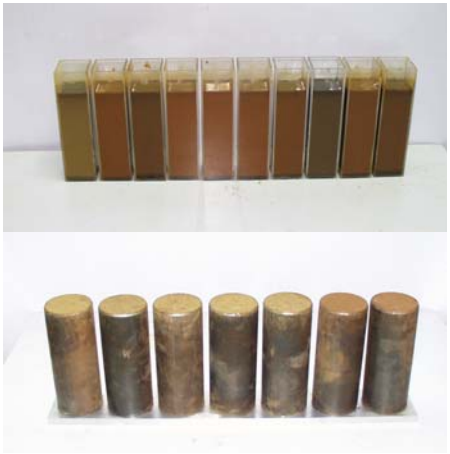

Figure 2. Soil particles samples dispersed in water (a) and undisturbed samples in steel cylinders (b).

The equipment has the following characteristics:

- Am-241 gamma-ray source (300 mCi);
- Platform for 10 samples;

- Vertical movement to scan the sample;
- Horizontal movement for sample positioning;
- Controlled by a PC computer;
- Electronic based on micro-controller 80535;
- Runs under Windows® 95 or later;
- Software developed in Microsoft Visual Basic® 4.0 32 bits.

Particle size distribution analysis

Dispersed particles falling in water are measured for several heights (h) and times (t) and the particle size distribution is determined according to the method introduced by Vaz et al. (1992), Oliveira et al. (1997) and Naime et al. (2001).

Results of soil particle size distribution of 24 samples (6 soils, 4 depths) and a comparison between the gamma-ray and the densimeter method are presented for 236 soil samples.

Soil Particle Density

A linear experimental correlation between the particle density determined by picnometer method and the mass attenuation coefficient measured with the equipment allows the particle density estimation (Vaz et al. 1999).

This experimental correlation is presented for 27 soil samples. Also, particle density of about 535 Brazilian soil samples estimated with this procedure, are presented.

Soil Water Retention Curves

Using a modification of Arya and Paris (1981) model, the soil water retention curves are determined with the particle size distribution curve measured with the automatic gamma-ray attenuation equipment.

This modification includes a dependence of the fitting parameter α with the soil water content similarly to the ones suggested by Basile and D'Urso (1997) and Arya et al. (1999).

Results are presented for 24 soil samples (6 soils, 4 depths) and compared with the experimental retention curves measured in laboratory for undisturbed samples.

Soil bulk density and water content profile

Undisturbed soil samples collected in steel cylinders (diameter = 7.8 cm, height = 18 cm) are vertically scanned in increment of 2 mm or longer. Wet samples are initially measured, then it is oven dried at 100^{o} C for 24h and again measured at the same points of the wet sample, allowing the determination of both bulk density and water content soil profile.

Results of 5 collected soil samples, 18 cm long, are presented, with bulk density and water content determined each 5 mm along the samples.

Results

Particle size distribution curves

Figure 3 presents the complete particle size distribution curves of 24 Brazilian soil samples. In Figure 4 it is presented a validation of the equipment and the methodology with the densimeter method. A good linear correlation coefficient was obtained (r^2 = 0.94) and RMSE = 5,03) for all fractions together.

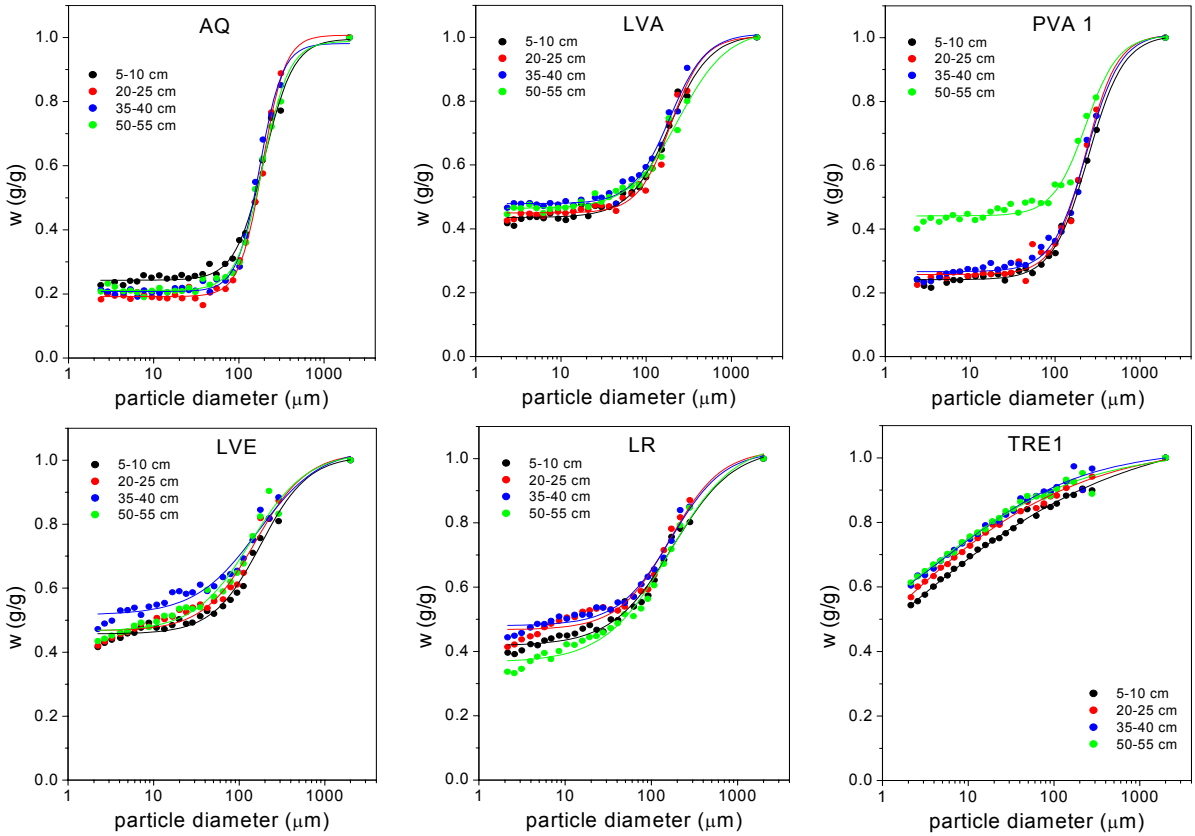

Figure 3. Particle size distribution of 6 Brazilian soil at 4 depths each, measured with the automatic gamma-ray attenuation equipment. AQ, LVA, LR, LVE and TRE are Oxisols and PVA is an Ultisol

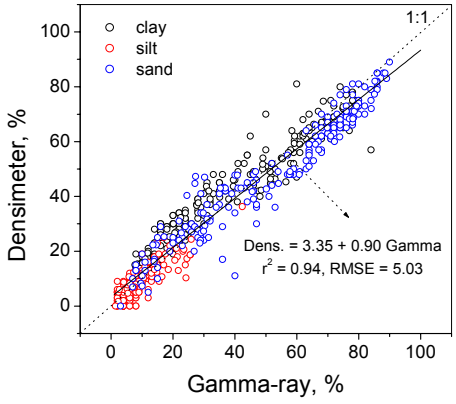

Figure 4. Granulometric fractions of 236 Brazilian soil samples, measured by densimeter and gamma ray-attenuation methods.

Soil Particle Density

Figure 5 shows the empirical correlation obtained between the mass attenuation coefficient and the soil particle density. The good linear correlation allows good estimation of the ρ_p parameter. A distribution of ρ_p for 535 Brazilian soils are presented in Figure 6. Basically, 3 groups of ρ_p can be identified.

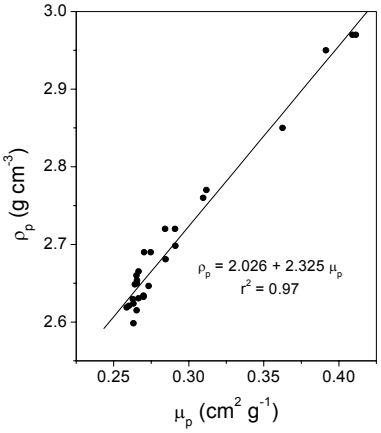

Figure 5. Correlation between the soil mass attenuation coefficient (μ_p) and the soil particle density (ρ_p) for 27 Brazilian soil samples.

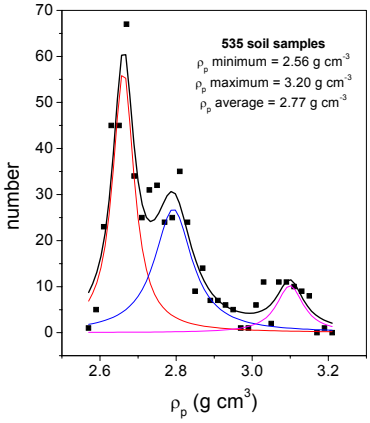

Figure 6. Histogram of particle density for 535 Brazilian soil samples, estimated by the mass attenuation coefficient.

Soil Water Retention Curves

Figure 7 shows estimated and measured water retention curves of 6 different soils (AQ, LVA, LVE, LR and TRE are Oxisols and PV is Ultisol). The fitting parameter α (Arya and Paris, 1981) was assumed as h and θ dependent, as suggested by Basile and D'Urso, 1997) and its dependence is showed in Figure 8 for 24 soil samples.

The performances of the α variable procedure and the constant (0.938, Arya and Dierolf, 1992) one are compared in Figure 9. It can be seen a good improvement of θ estimation when using the α variable assumption.

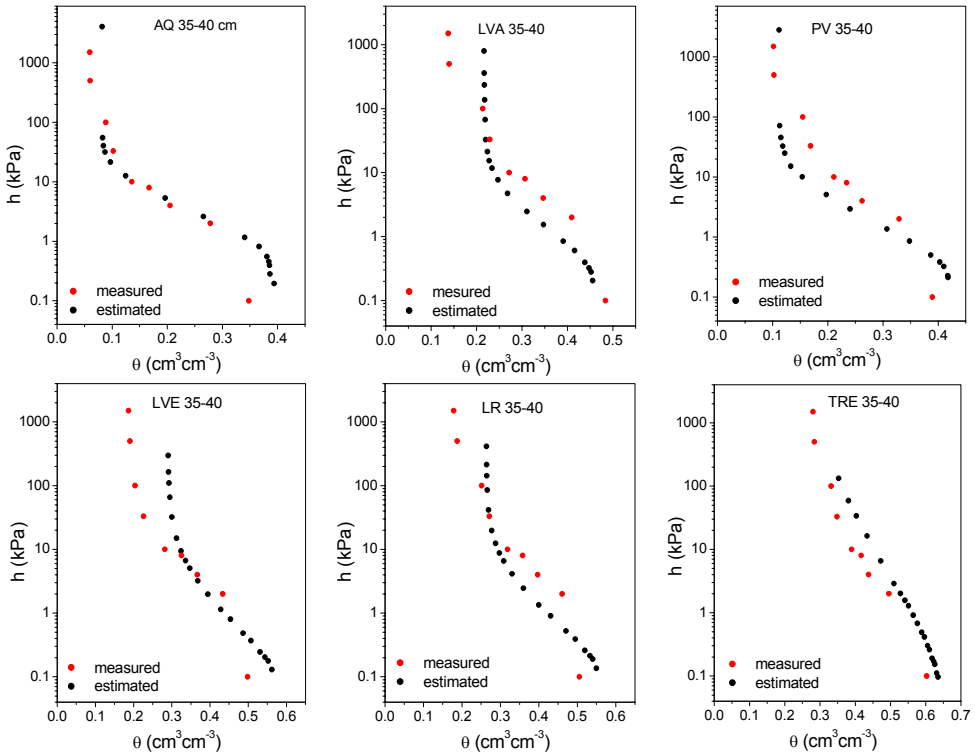

Figure 7. Retention curves measured and estimated by the Arya and Paris method modified for the fitting parameter α as a function of the soil water content and potential (Basile and D'Urso, 1997).

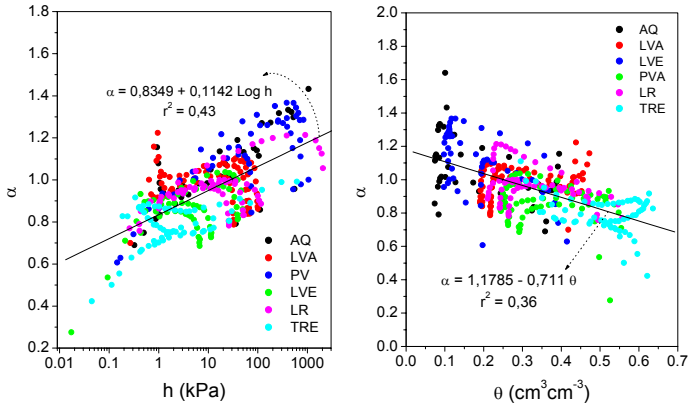

Figure 8. Dependence of the fitting parameter α with the soil water content and potential, for 24 Brazilian soil samples.

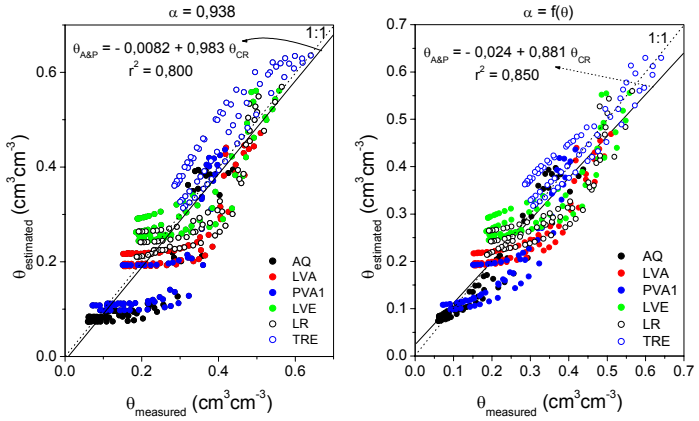

Figure 9. Water content estimated by the modified Arya and Paris method for the fitting parameter α=0.938 (Arya and Dierolf, 1992) and α = f(α) (Figure 7).

Soil bulk density and water content profile

Bulk density and water content variation of 5 soil samples (Oxisol-LVA), 18 cm long, are presented in Figure 10. The equipment allows determination of detailed profile of both parameters.

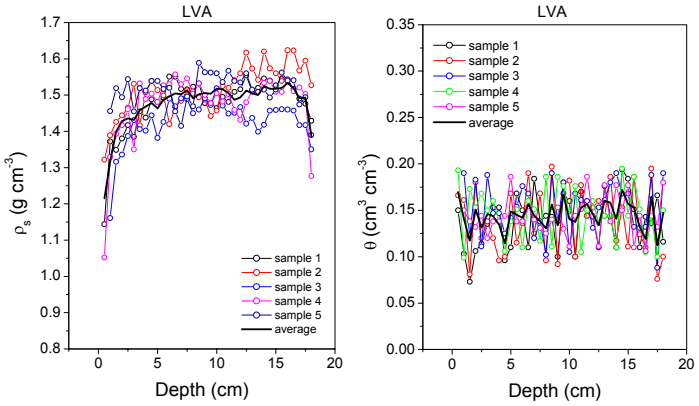

Figure 10. Soil bulk density and water content profile measured for the LVA soil with a spatial resolution of 5mm.

Conclusions

The automatic gamma-ray attenuation equipment allows determination of several soil physical parameters with good accuracy . Best advantages are the possibility of easily estimate some parameters like particle density and water retention curves, and determine precisely and fast the soil particle size distribution or granulometry, bulk density, porosity and water content.

Measurement of other physical parameters as hydraulic conductivity and even chemical parameters as pH, electrical conductivity, ion concentration and others (using convenient sensors) can be, in principle measured or estimated, with the automated equipment and has been investigated.

References

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