3rd BRAZILIAN SOIL PHYSICS MEETING
III ENCONTRO BRASILEIRO DE FÍSICA DO SOLO
May 04 - 08, 2015

Application of computed tomography (CT) to soil physics in Brazil from 1985-2015

Luiz Fernando Pires, Sc. D.

Laboratory of Soil Physics and Environmental Sciences, Department of Physics State University of Ponta Grossa (UEPG), CEP 84.030-900, Ponta Grossa, PR, Brazil – E-mail Address: lfpires@uepg.br

Presentation Outline

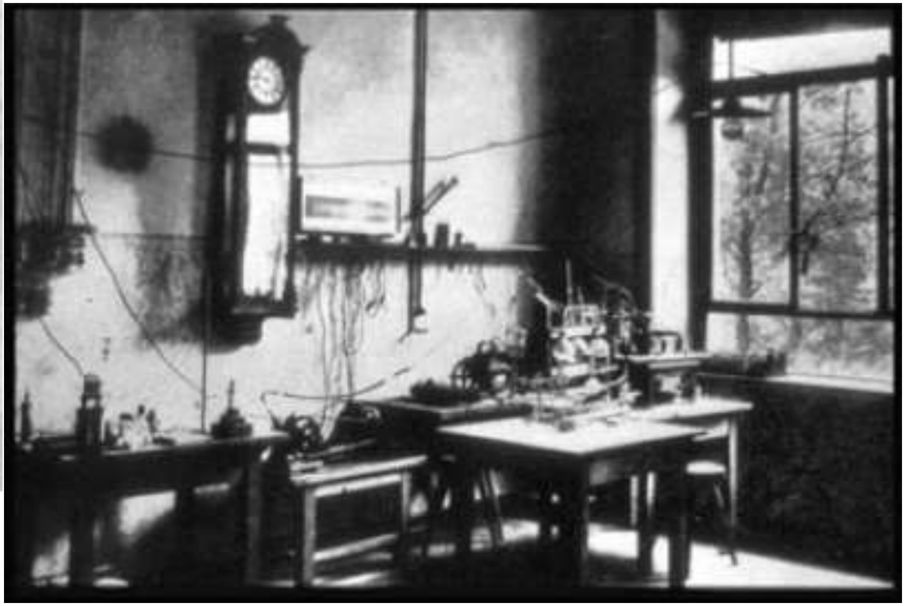
- History – X-ray, Radioactivity and CT;
- Basic Concepts – Attenuation and CT;
- CT Applications in Soil Physics;
- Future Works;
- Conclusions

HISTORICAL OVERVIEW

History

- **Wilhelm C. Roentgen (1895) – X-ray Discovery**

Nobel Prize (1901) - Physics

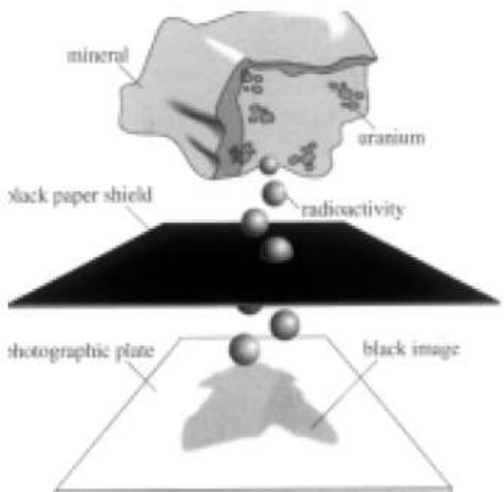


R. Cierniak, *X-Ray Computed Tomography in Biomedical Engineering*, DOI: 10.1007/978-0-85729-027-4_2, © Springer-Verlag London Limited 2011

History

- **Henri Becquerel (1896) – Radioactivity Discovery**

Nobel Prize (1903) - Physics



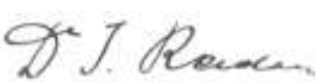
Rock resting on covered film.

Shadow on developed film.

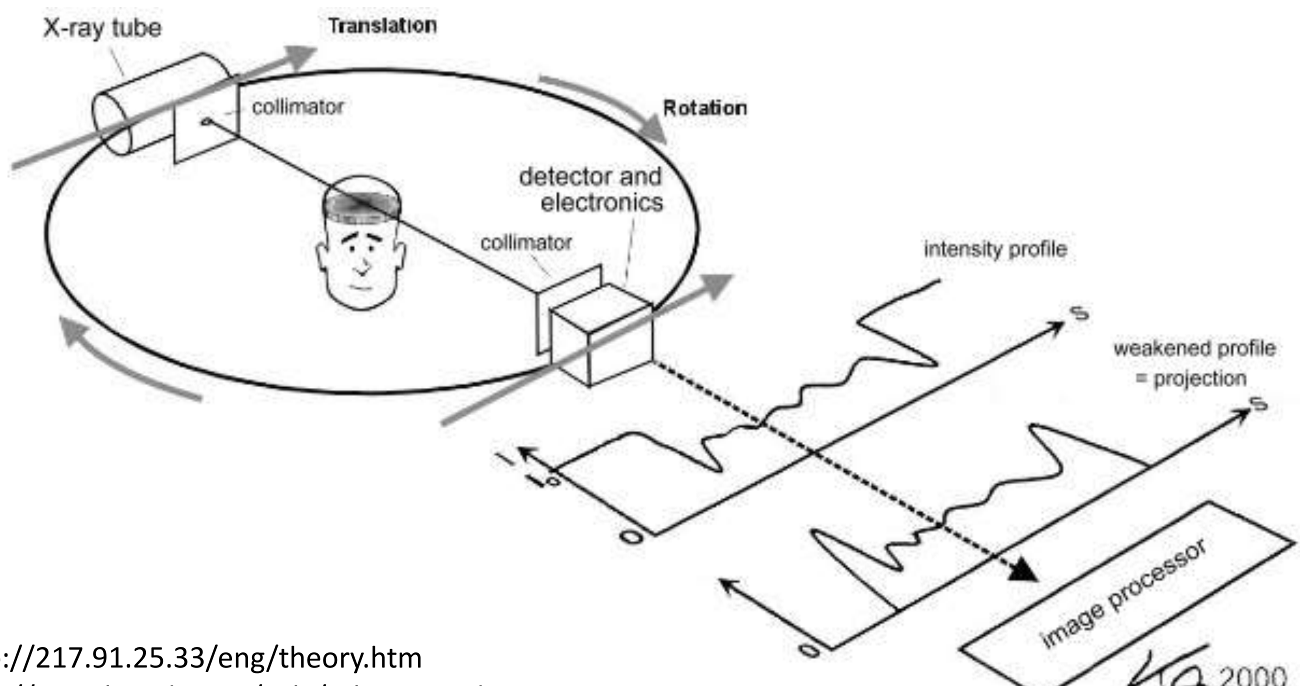
http://www.rsc.org/images/essay1_tcm18-17763.pdf
http://www.ck12.org/book/CK-12-Chemistry---Second-Edition/section/24.1/
http://www.orcbs.msu.edu/radiation/resources_links/historical_figures/becquerel.htm
http://en.wikipedia.org/wiki/Henri_Becquerel#/media/File:Becquerel_plate.jpg

History

- Johann Radon (1917) – Basis of methods of image reconstruction from projections



$$R(\rho,\theta) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\delta(\rho - x\cos\theta - y\sin\theta)\,dx\,dy$$

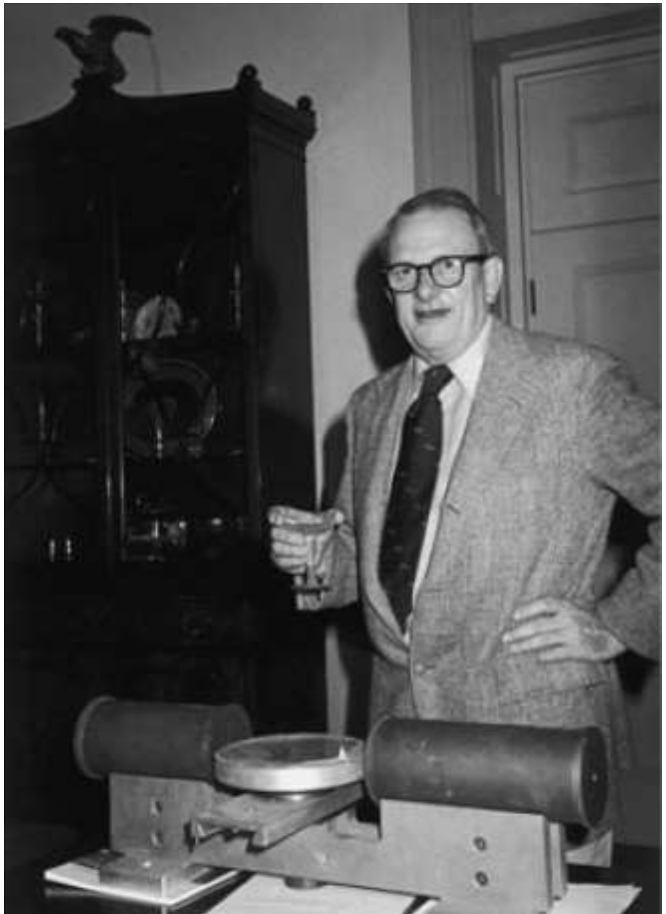


http://217.91.25.33/eng/theory.htm
http://en.wikipedia.org/wiki/Johann_Radon

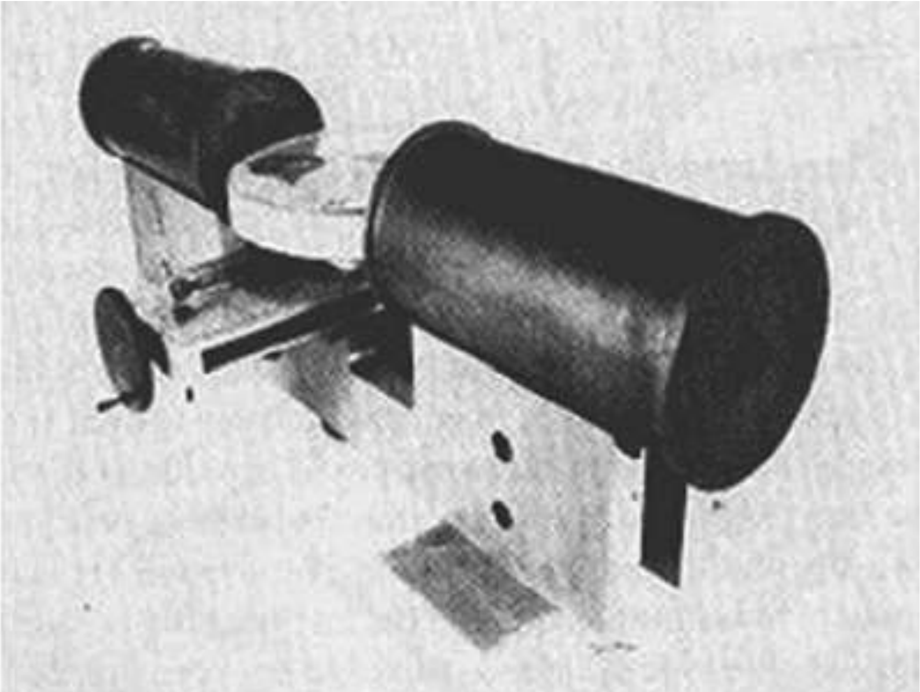
History

- **Allan Cormack (1963) – Image Reconstruction**

Nobel Prize (1979) - Medicine



Tomographic device built by Cormack in 1963



R. Cierniak, *X-Ray Computed Tomography in Biomedical Engineering*, DOI: 10.1007/978-0-85729-027-4_2, © Springer-Verlag London Limited 2011

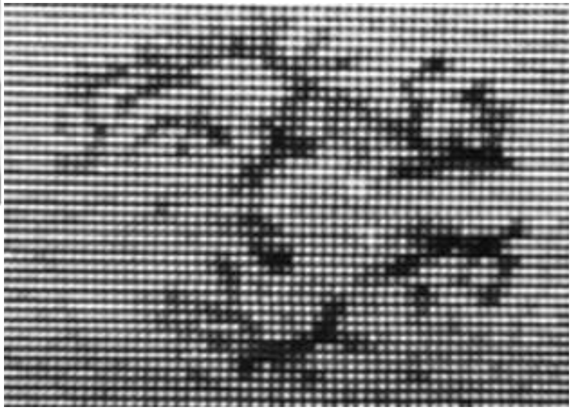
History

- Godfrey Hounsfield (1973) – CT equipment

Nobel Prize (1979) - Medicine

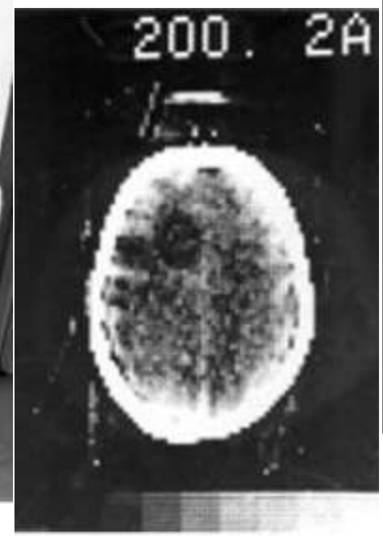
Laboratory scanner used by G.N. Hounsfield

an image of a preserved brain obtained in 1968



R. Cierniak, *X-Ray Computed Tomography in Biomedical Engineering*, DOI: 10.1007/978-0-85729-027-4_2, © Springer-Verlag London Limited 2011

History

The EMI Mark I scanner (**a**) and a transverse image of the brain (**b**)

R. Cierniak, *X-Ray Computed Tomography in Biomedical Engineering*,
DOI: 10.1007/978-0-85729-027-4_2, © Springer-Verlag London Limited 2011

History

- **Petrovic et al. (1982) – Proc. Soil Sci. Soc. Am.**
- **Hainsworth & Aylmore (1983) – Aust. J. Soil Res.**
- **Crestana et al. (1985) – Soil Science – (Brazil)**

History

- **Petrovic et al. (1982)**

Paper: ***Soil Bulk Density Analysis in Three Dimensions by Computed Tomographic Scanning*****, by AM Petrovic, JE Siebert and PE Rieke, Proc. Soil Sci. Soc. Am. 46(3), 445-450**

"The x-ray transmission computed tomography (CT) scanner was evaluated as a tool to determine soil bulk density. For the Metea sandy loam soil (Arenic Hapludalfs), this CT scanner was found to have precision in the order of 19 mg/cm3. Spatial resolution or the ability to distinguish between two objects in the scanning plane was found to range from 1.25 by 1.25 by 2 mm^3 to 6.4 mm in diameter by 2 mm. This is a potentially promising tool for research in the areas of compaction, soil management, and cultivation."

History

- **Hainsworth & Aylmore (1983)**

Paper: ***The use of computer assisted tomography to determine spatial distribution of soil water content***, **by JM Hainsworth and LAG Aylmore, Australian J. Soil Res. 21(4), 435- 443**

"To date no experimental technique has been capable of directly and repetitively measuring spatial distributions of soil water content in a non-destructive manner. The potential of computer assisted tomography (CAT) to overcome this problem has been examined in this paper. The results obtained from a commercially-produced X-ray CAT scanner and a conventional gamma scanner suggest that CAT scanning can be used to determine spatial changes in soil water content with adequate resolution for soil-plant studies."

History

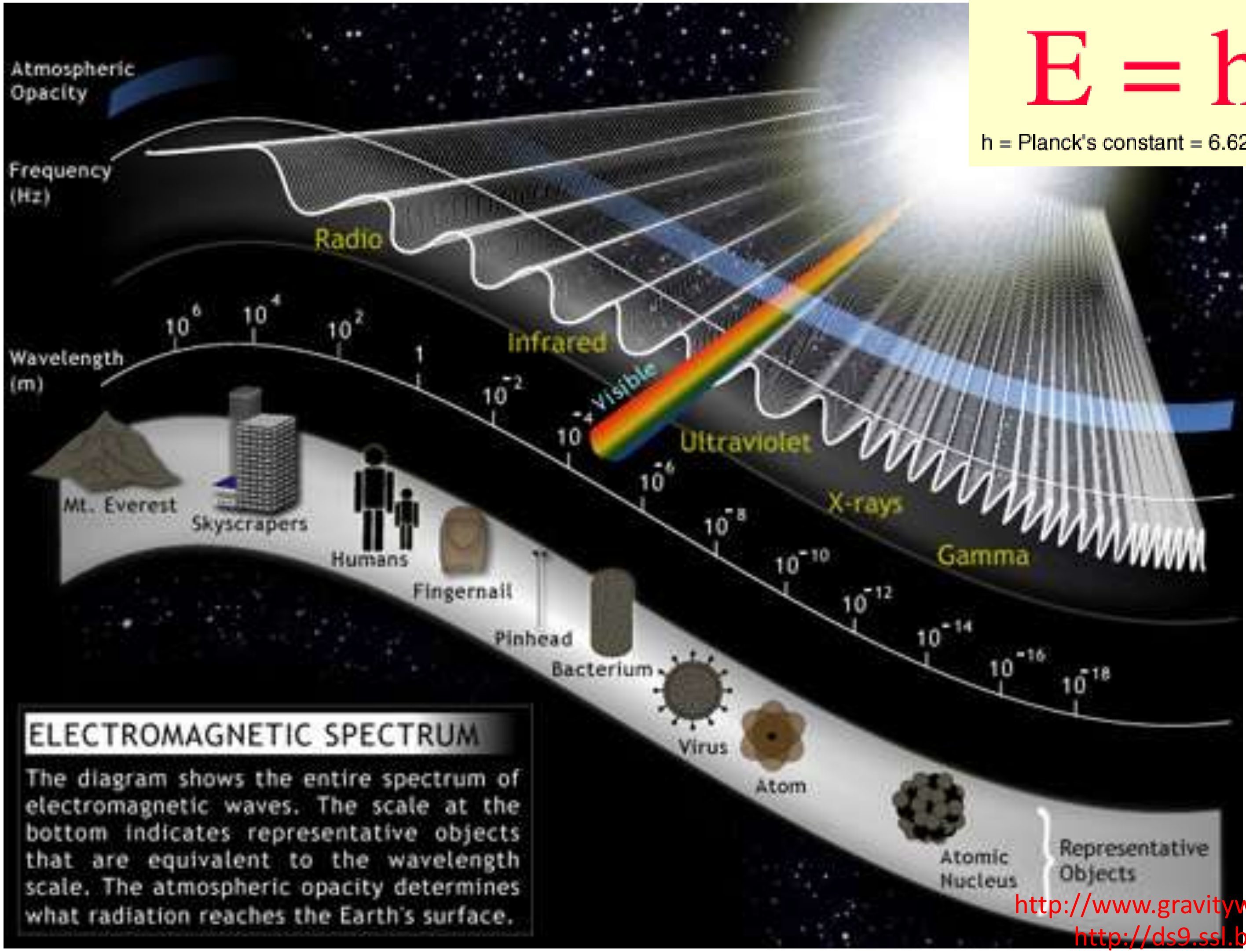
- **Crestana et al. (1985)**

Paper: ***Static and dynamic three-dimensional studies of water in soil using computed tomographic scanning*****, by S Crestana, S Mascarenhas, R Pozzi-Mucelli, Soil Science 140(5), 326–332.**

"Previous work of Petrovic et al. (1982) demonstrated the possibility of using x-ray transmission, computed tomography (CT) scanning for soil bulk density analysis in soil. We show that CT can also be used for measuring the water content of soil. We also show that CT can be applied to measure and follow dynamically the motion of water in soil in three dimensions. The use of CT for water content and motion in soil in three dimensions opens new possibilities in this area of investigation."

BASIC CONCEPTS

Basic theoretical background - Attenuation



frequency of radiation, sometimes written as f giving expression E = hf.

$$E = h\nu$$

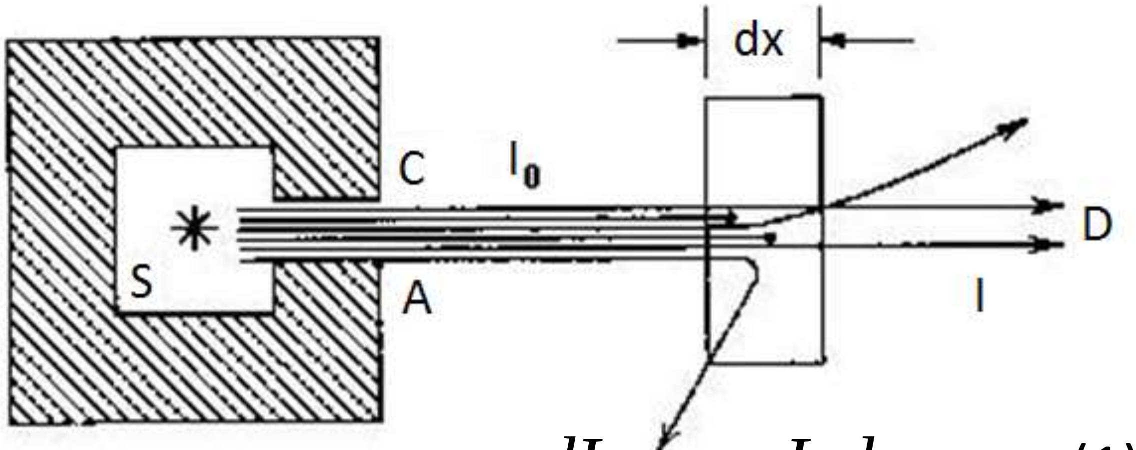
Quantum energy of a photon.

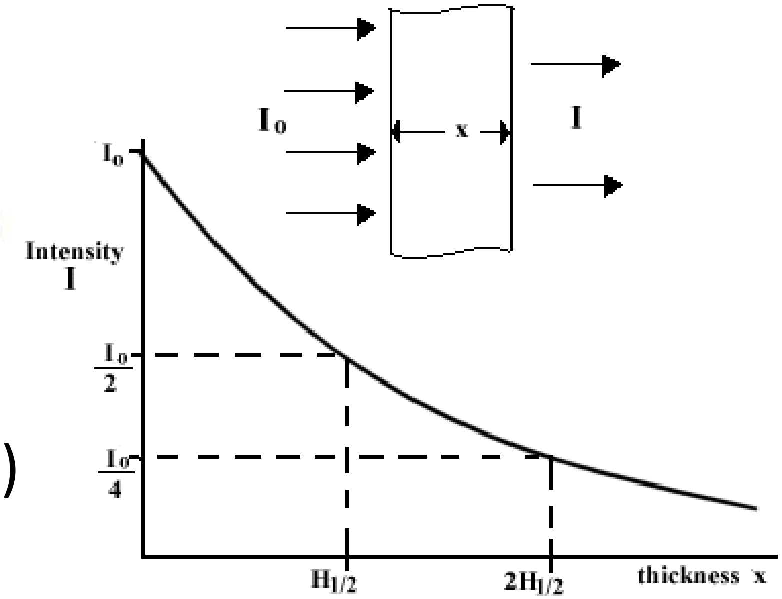
h = Planck's constant = 6.626×10^{-34} Joule·sec = 4.136×10^{-15} eV·s

$$E = h.f$$

http://www.gravitywarpdrive.com/NGFT_Chapter_10.htm
http://ds9.ssl.berkeley.edu/LWS_GEMS/2/espec.htm

Basic theoretical background - Attenuation





$$dI = -\kappa . I_0 dx \qquad (1)$$

$$\int_{I_0}^{I} \frac{dI}{I} = -\kappa \int_0^x dx \qquad (2)$$

$$I = I_0 \exp(-\kappa . x) \qquad (3)$$

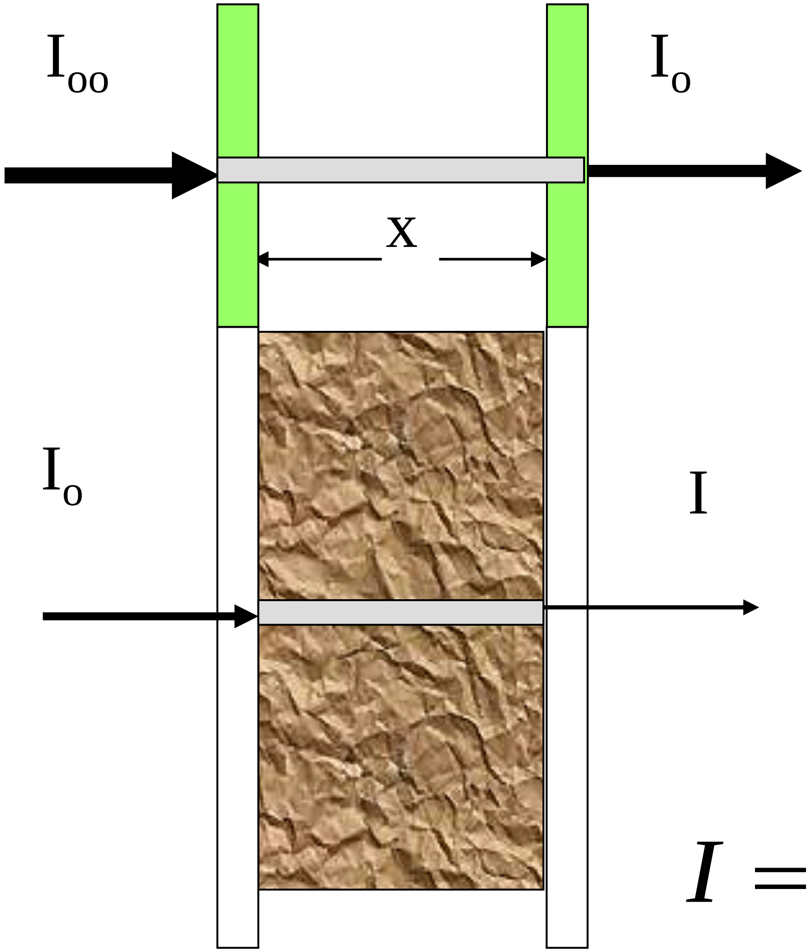
$$\mu = \tau(Ph) + \varepsilon(C) + \kappa(PP) \qquad (4)$$

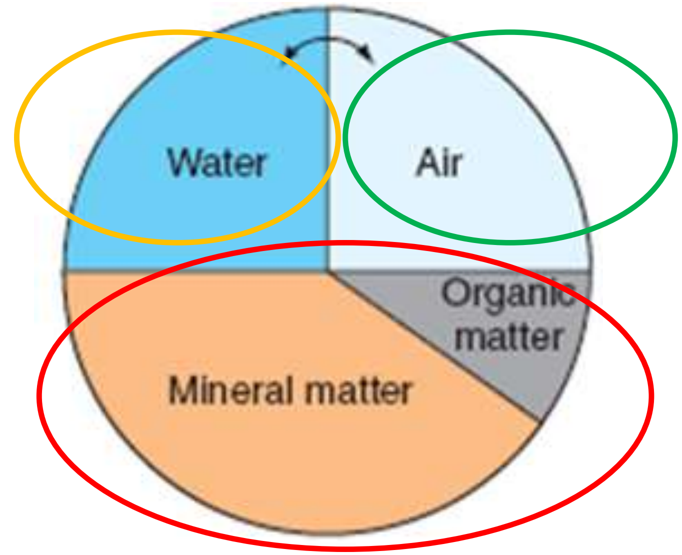
$$\mu = \frac{\kappa}{\rho} \qquad (5)$$

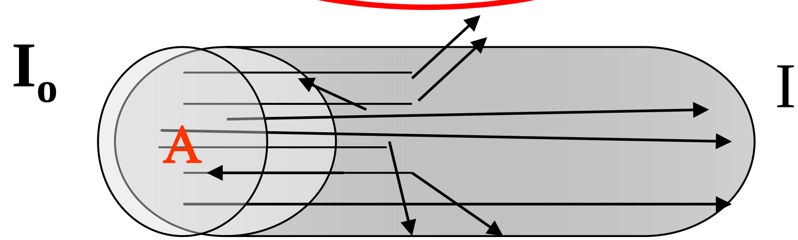
$$\left(\frac{\kappa}{\rho}\right) = \sum_{i=1}^{n} w_i . \left(\frac{\kappa}{\rho}\right)_i \qquad (6)$$

http://www.keele.ac.uk/dohs/radiation/intro/

Basic theoretical background - Attenuation







$$I = I_0 e^{-\mu_p \cdot \rho_p \cdot x_p - \mu_w \cdot \rho_w \cdot x_w - \mu_{air} \cdot \rho_{air} \cdot x_{air}}$$

Basic theoretical background - Attenuation

$$d_s = \frac{x_p.A.\rho_p}{X.A} \quad \therefore \quad x_p = \frac{d_s.X}{\rho_p}$$

The attenuation through the air can be disregarded

$$\theta = \frac{x_w.A.\rho_w}{X.A} \quad \therefore \quad x_w = \theta.X$$

$$I = I_0 e^{-X(\mu_p d_s + \mu_w d_w \theta)}$$

=0

If we measure d_s, μ_p, μ_w and X : $\Rightarrow \theta$

Dry soil: $\Rightarrow \quad I = I_0 e^{-X\mu_p d_s} \quad \Rightarrow$ **d_s Evaluation**

Basic theoretical background - Attenuation

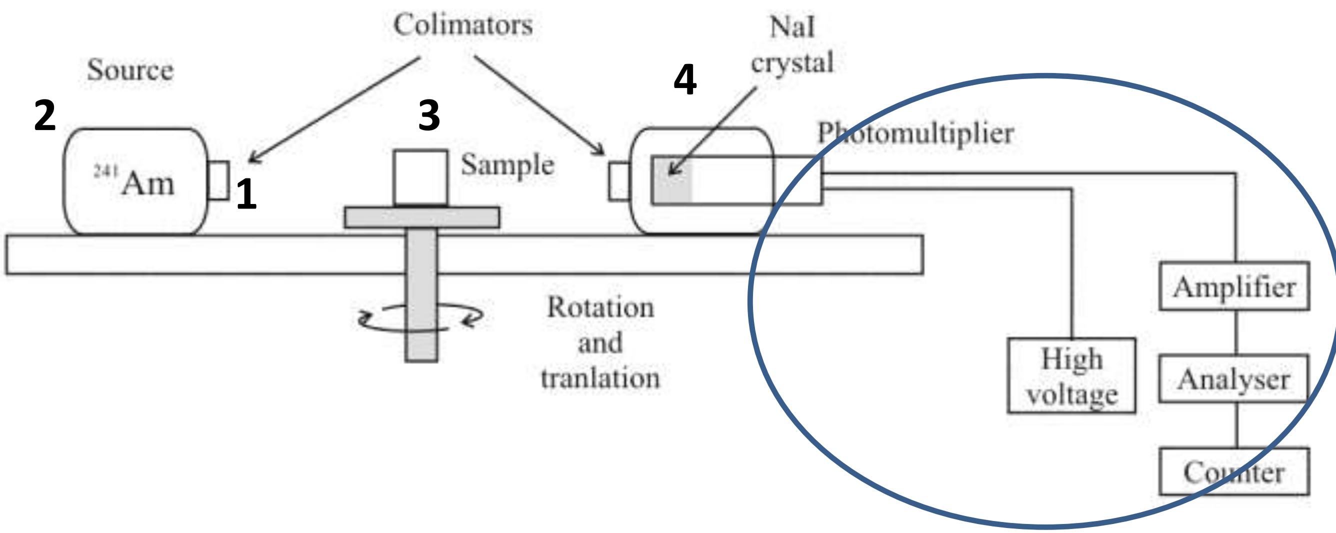
$$I_{(Am)} = I_{0(Am)} \exp - X[\mu_{s(Am)} d_s + \mu_{w(Am)} \theta]$$

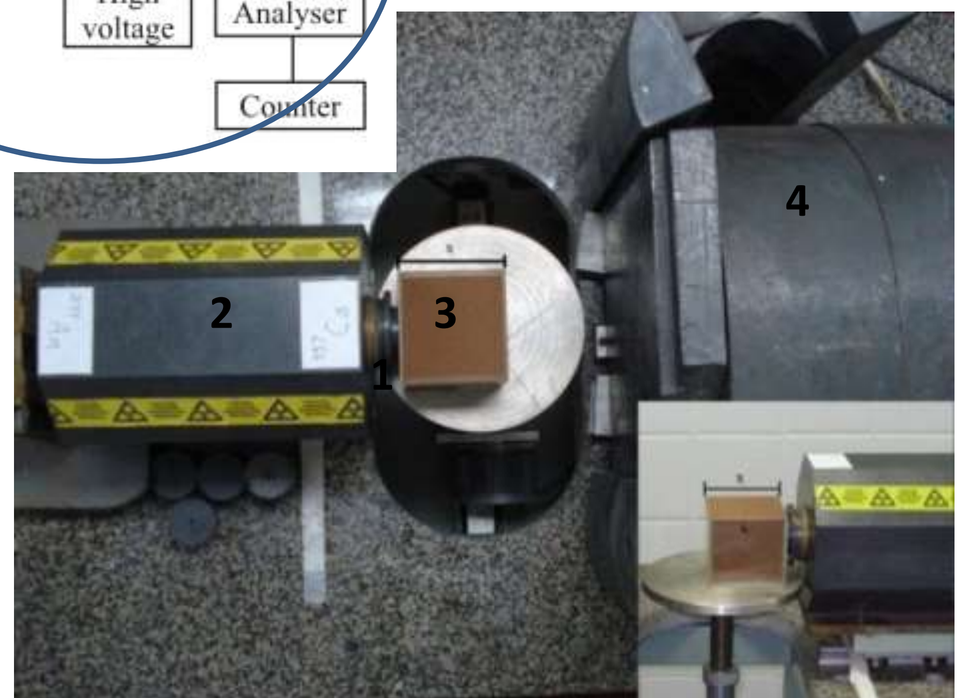
$$I_{(Cs)} = I_{0(Cs)} \exp - X[\mu_{s(Cs)} d_s + \mu_{w(Cs)} \theta]$$

$$\theta = \frac{\mu_{p(Am)} . \ln(\frac{I_0}{I})_{(Cs)} - \mu_{p(Cs)} . \ln(\frac{I_0}{I})_{(Am)}}{X(\mu_{p(Am)} . \mu_{w(Cs)} - \mu_{p(Cs)} . \mu_{w(Am)})}$$

$$d_s = \frac{\mu_{w(Cs)} \ln(\frac{I_0}{I})_{(Am)} - \mu_{w(Am)} \ln(\frac{I_0}{I})_{(Cs)}}{X(\mu_{p(Am)} . \mu_{w(Cs)} - \mu_{p(Cs)} . \mu_{w(Am)})}$$

Basic theoretical background - CT





Lead castle containing radioactive sources, acrylic box with a sample with thickness x and lead shield containing the detector and schematic representation of the CT scanner of first generation. The lower corner (right) shows a panoramic view of the sample container

Basic theoretical background - CT

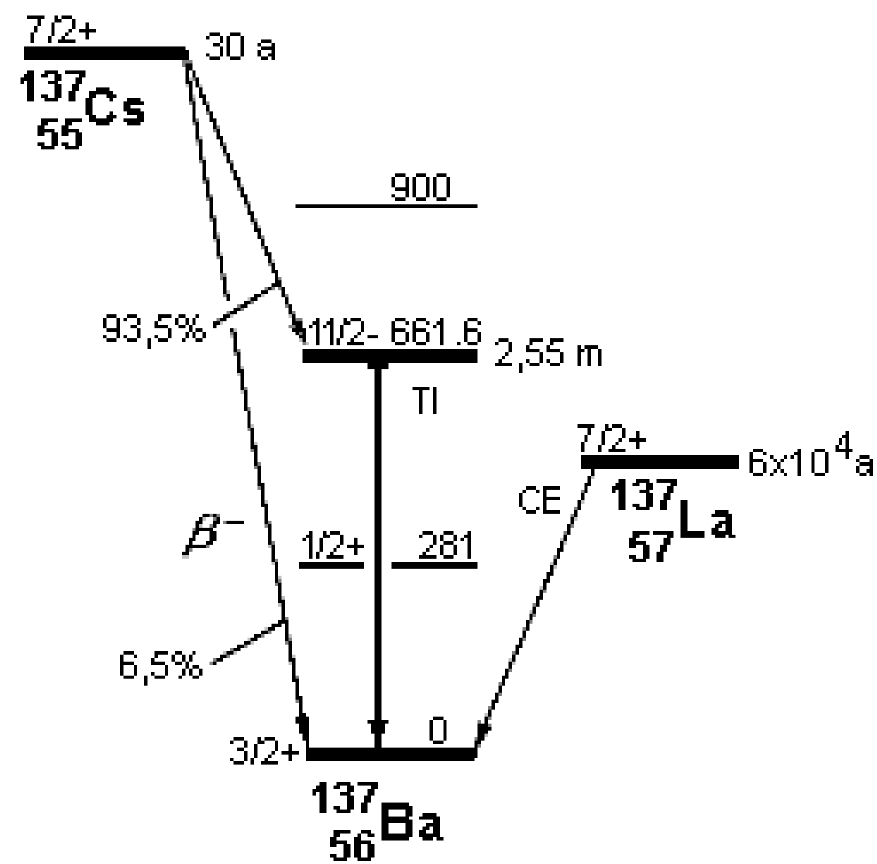
$$^{241}_{95}Am \rightarrow [^{237}_{93}Np] + ^{4}_{2}\alpha + \gamma(60\,keV)$$

$T_{1/2}$ = 458 years

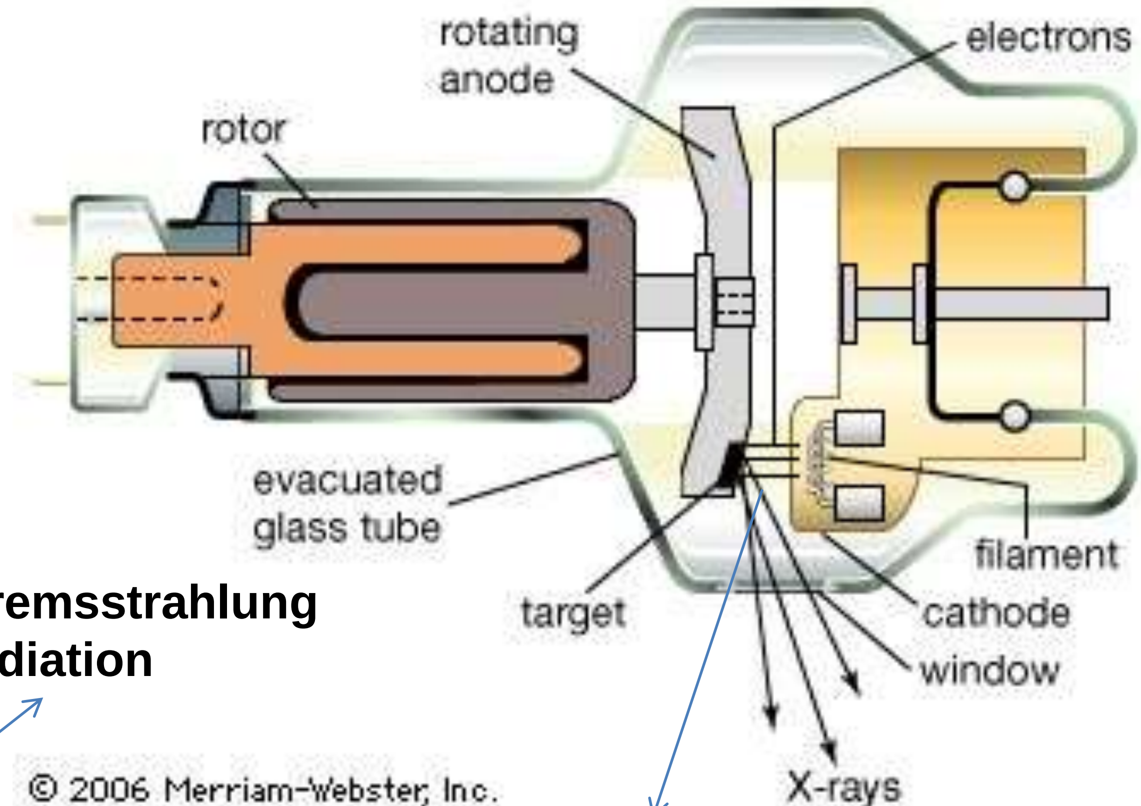
$$^{137}_{55}\mathrm{Cs} \rightarrow [^{137}_{56}\mathrm{Ba}] \rightarrow$$

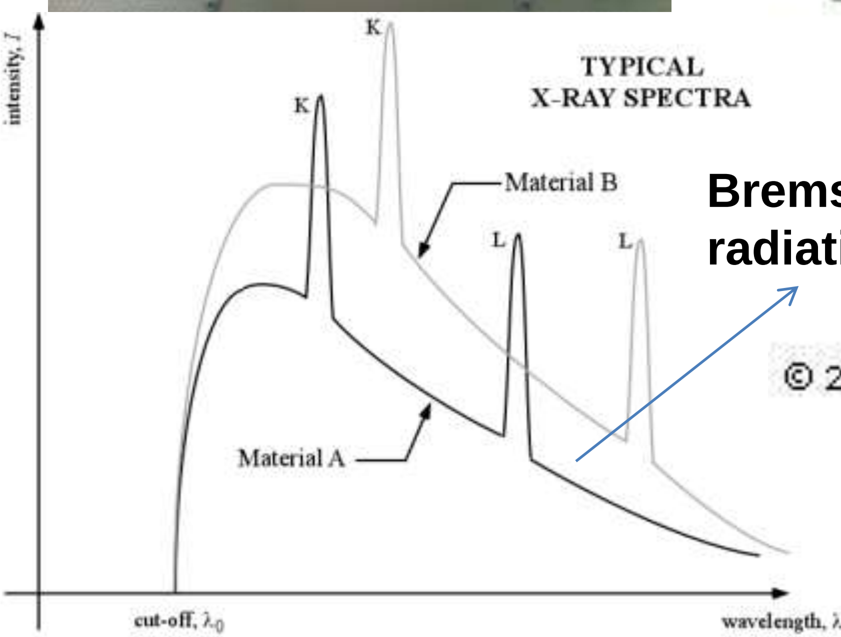
$$^{137}_{56}\mathrm{Ba} + \beta^{-} + \gamma\,(661.6\,\mathrm{keV})$$

$T_{1/2}$ = 30 years



Basic theoretical background - CT





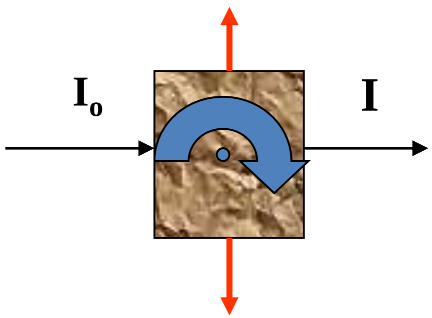
Bremsstrahlung radiation

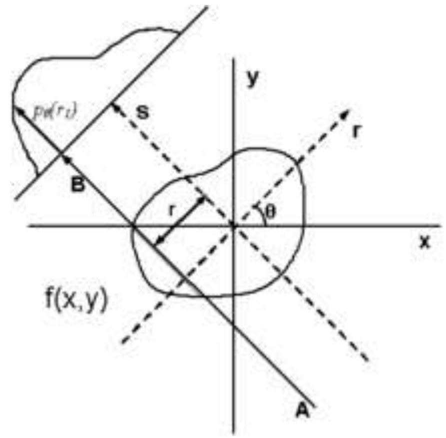
Potential difference

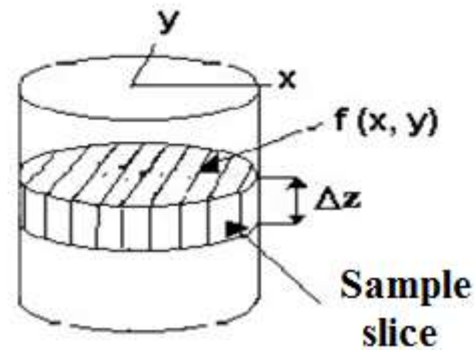
http://www.wikiradiography.net/page/Physics+of+the+X-Ray+Tube

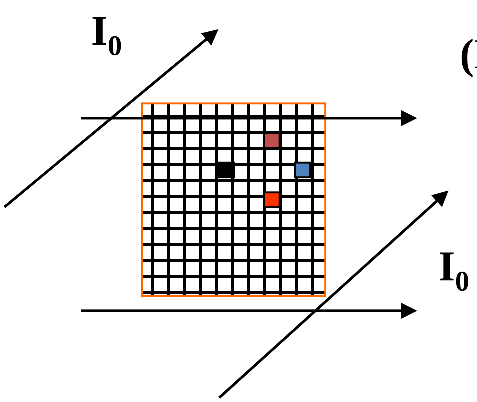
http://commons.wikimedia.org/wiki/File:Old_x_ray_tube_valugi_2.jpg

Basic theoretical background - CT



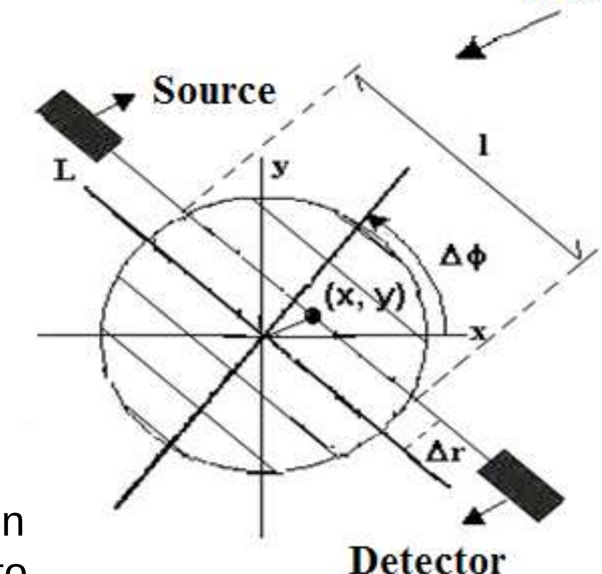






(I_0 = incident beam intensity)

Attenuation proportional to the material density

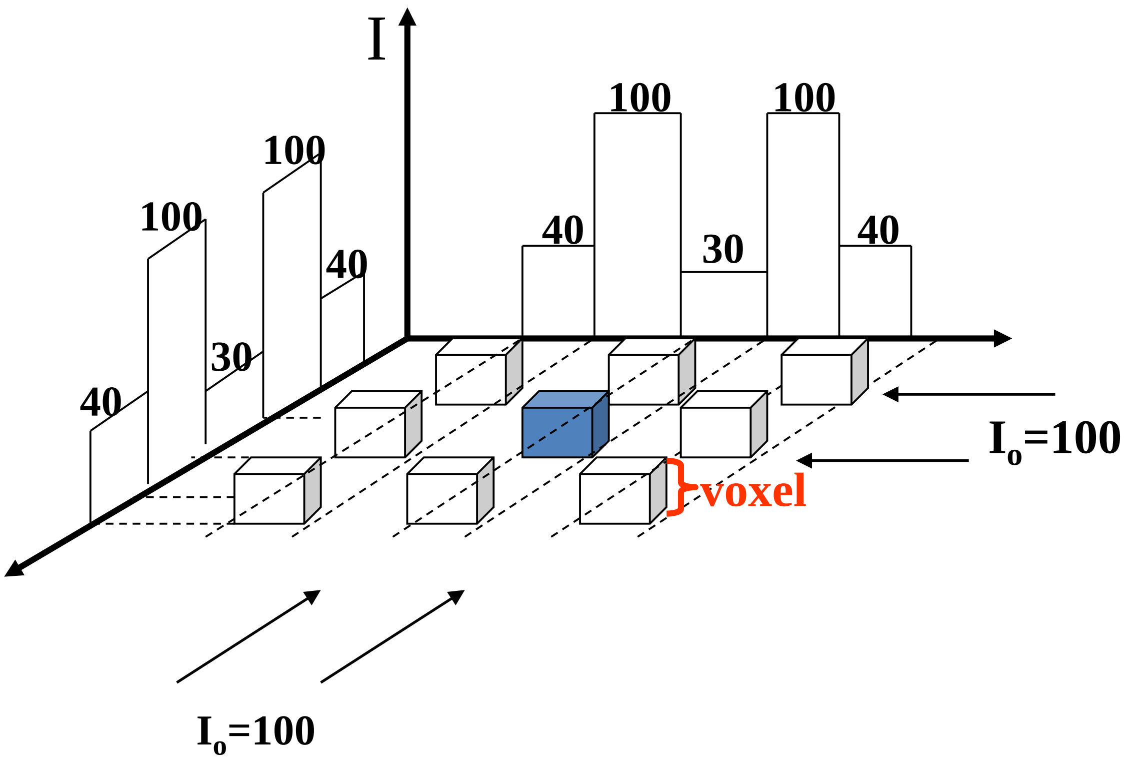


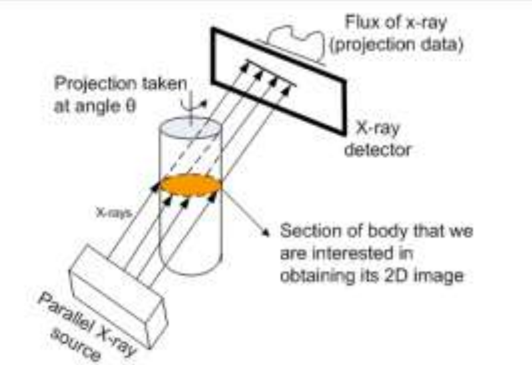
Beam attenuation in each direction allows the generation of a number (TU) related to κ in each crossing point. The differences in TU associated to each point of the soil matrix can be associated to differences in gray scales in reconstructed images.

http://en.wikipedia.org/wiki/Tomographic_reconstruction

Bacchi, O.O.S – Soil Physics Lectures – CENA/USP

Basic theoretical background - CT





Components of parallel X-ray CT system. Many projections are obtained at different angles. Projections are combined in software using filtered backprojection to obtain an accurate 2D image of the section of the body shown above.

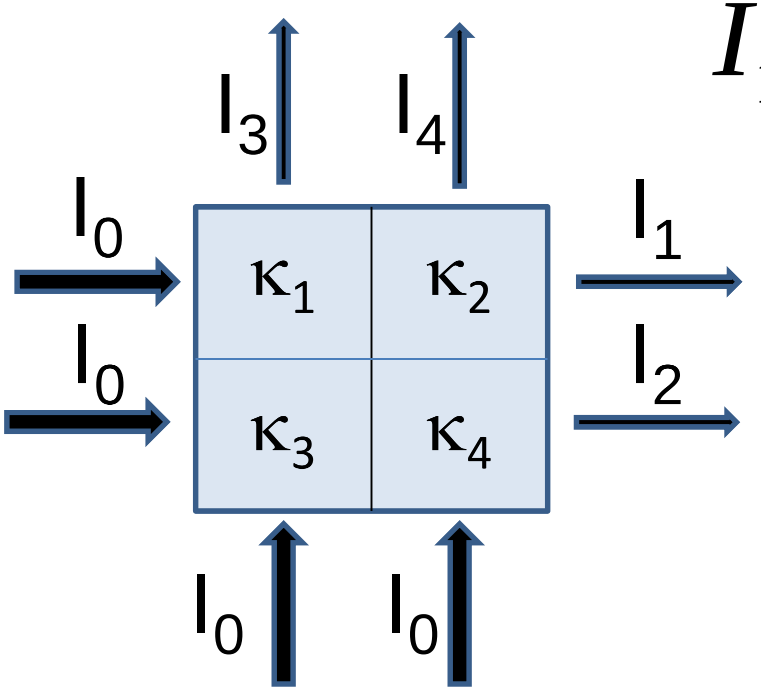
	20		20		20
	20		30		20
	20		20		20

} pixel

http://12000.org/my_notes/EE518_CT_project/REPORT/note_on_radon/note_on_radon.htm

Bacchi, O.O.S – Soil Physics Lectures – CENA/USP

Basic theoretical background - CT



$$I_1 = I_0 e^{-(\kappa_1 \Delta x + \kappa_2 \Delta x)}$$

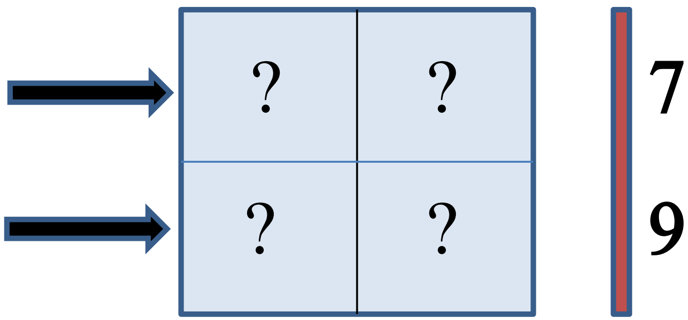
$$I_2 = I_0 e^{-(\kappa_3 \Delta x + \kappa_4 \Delta x)}$$

$$\begin{cases} \ln\left(I_0 / I_1 \right) = \kappa_1 \Delta x + \kappa_2 \Delta x \\ \ln\left(I_0 / I_2 \right) = \kappa_3 \Delta x + \kappa_4 \Delta x \\ \ln\left(I_0 / I_3 \right) = \kappa_3 \Delta y + \kappa_1 \Delta y \\ \ln\left(I_0 / I_4 \right) = \kappa_4 \Delta y + \kappa_2 \Delta y \end{cases}$$

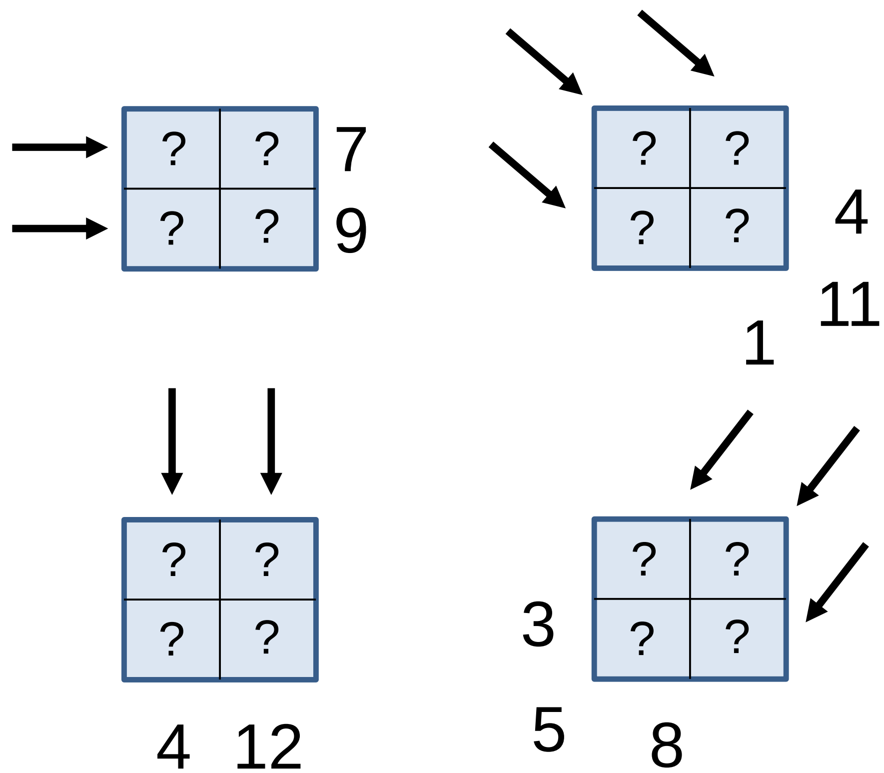
A minimum of 4 measurements is necessary to decompose an object into a 2 x 2 matrix

https://www.youtube.com/watch?t=163&v=gEQt5HacXJc

Basic theoretical background - CT



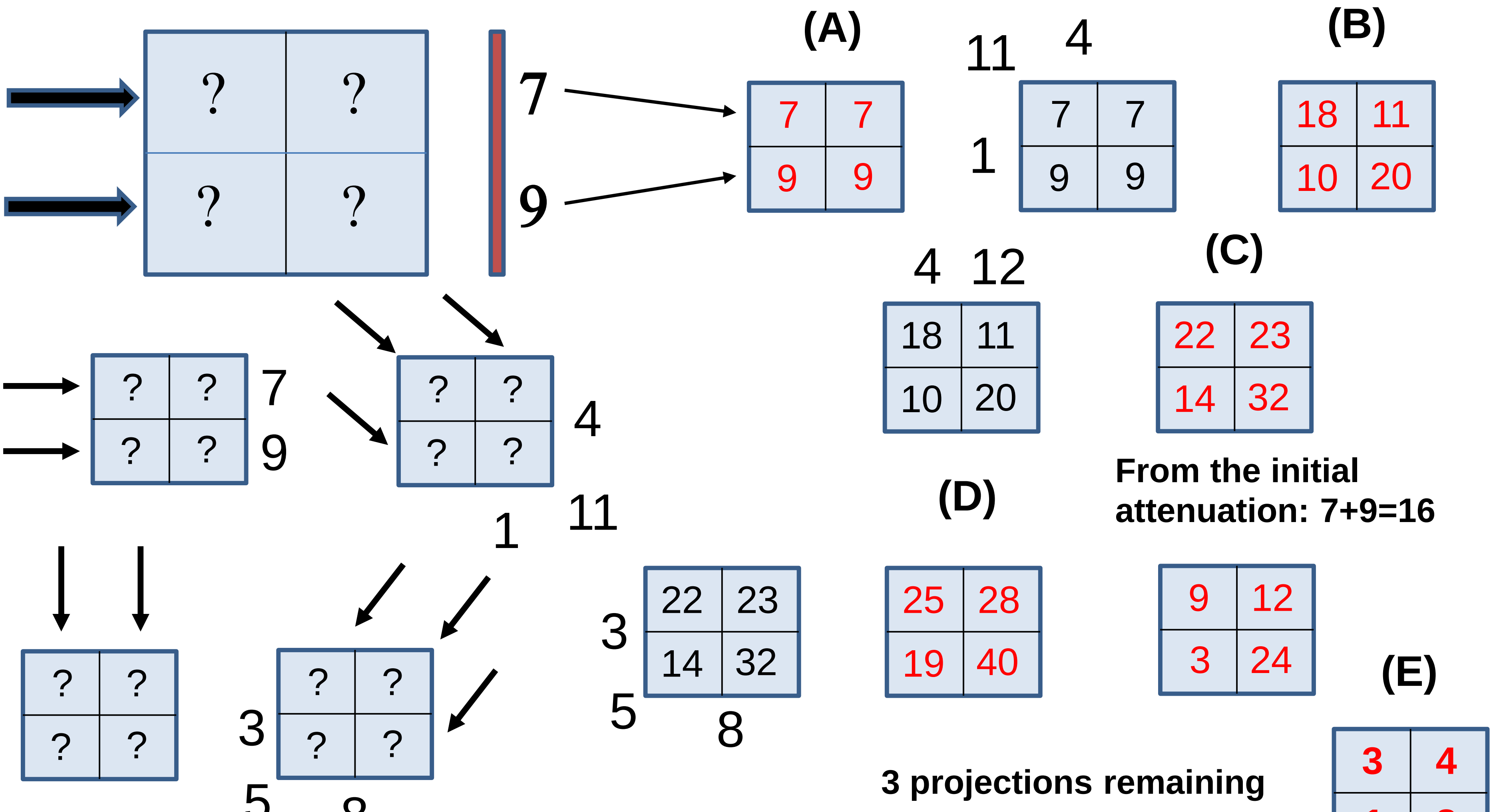
4 angles (directions of scan)
= 4 projections



Algorithms or formula to reconstruct the image and obtain the original information

https://www.youtube.com/watch?v=nSivTK6Icu4

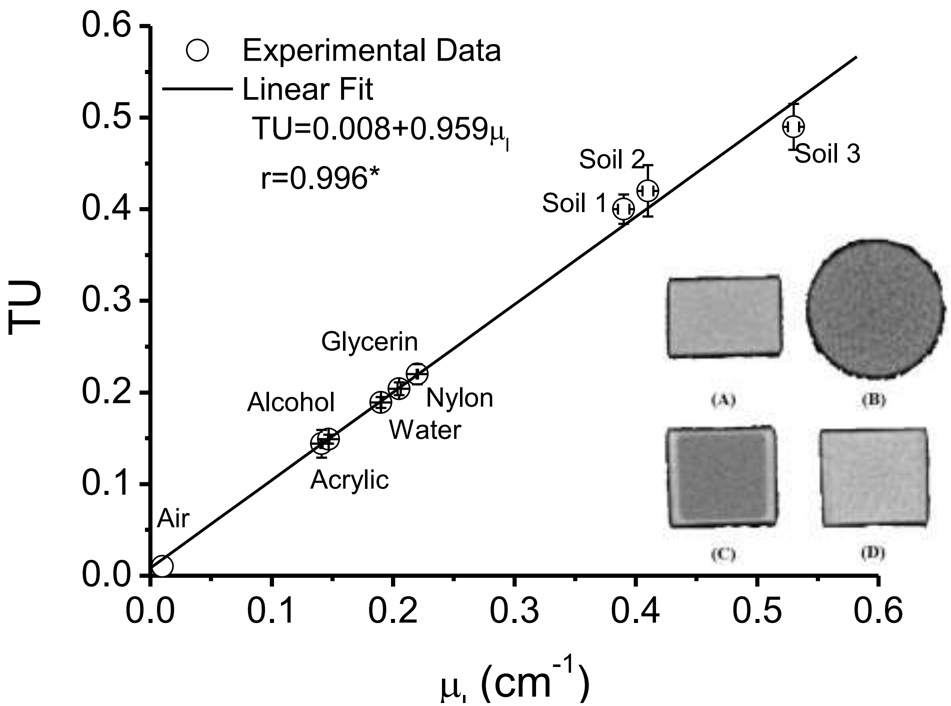
Basic theoretical background - CT



https://www.youtube.com/watch?v=nSivTK6Icu4

Basic theoretical background - CT

$$TU \propto \kappa = \alpha.\kappa = \alpha.(\mu_s.d_s + \mu_w.\theta.d_w)$$



Angular coefficient

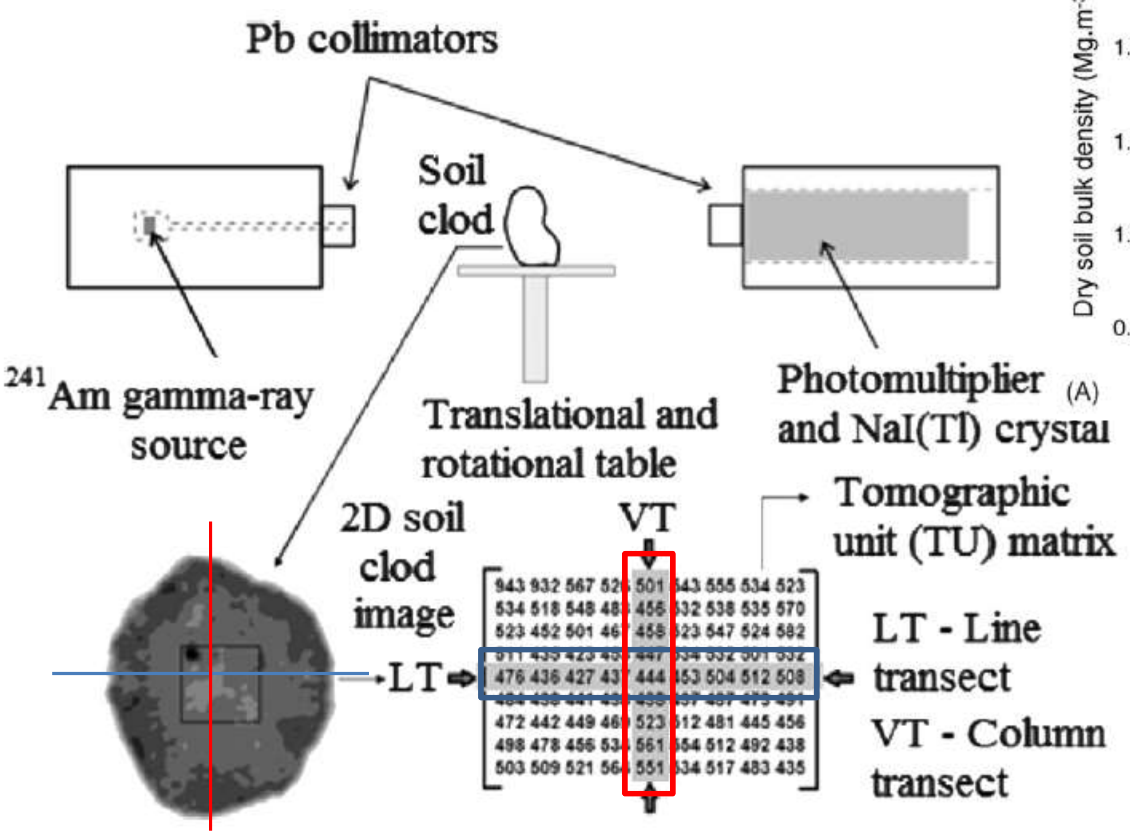
$$d_s = \frac{TU}{\alpha\left(\mu_s + \mu_w.\theta.d_w\right)}$$

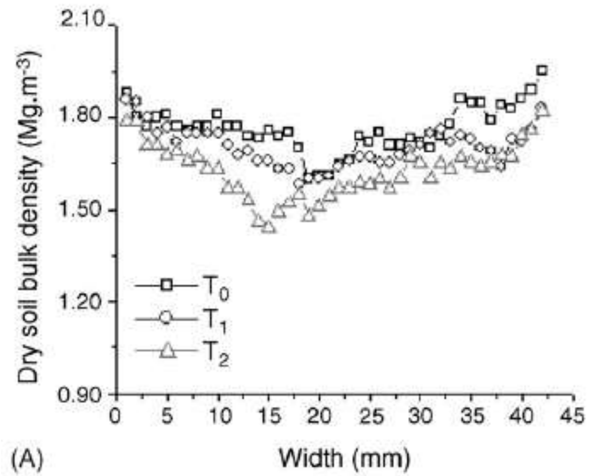
For a dry soil sample

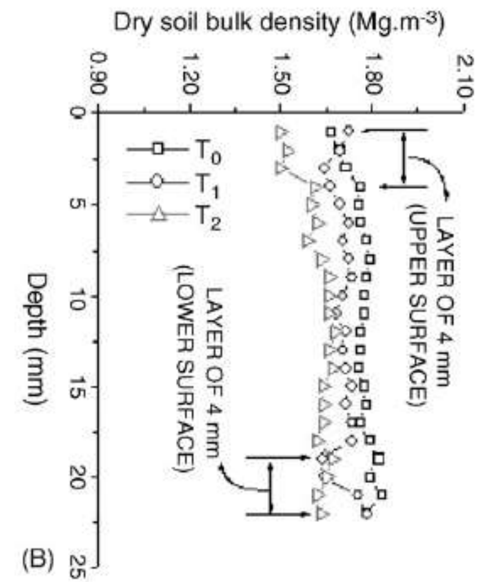
$$d_s = \frac{TU}{\alpha\mu_s}$$

TU takes the air as the medium with the minimum possible κ value. It is related to the Hounsfield Unit (HU) that takes the water as a reference medium for which HU=0

Basic theoretical background - CT







Pires et al. Applied Radiation and Isotopes, vol. 92, 37-45, 2014.
Pires et al. Soil & Tillage Research, vol. 94, 537-545, 2007.

SOME APPLICATIONS

Soil Science Studies

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Vol. 140, No. 5
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STATIC AND DYNAMIC THREE-DIMENSIONAL STUDIES OF WATER IN SOIL USING COMPUTED TOMOGRAPHIC SCANNING[1]

S. CRESTANA,[2] S. MASCARENHAS,[3] AND R. S. POZZI-MUCELLI[4]

Previous work of Petrovic et al. (1982) demonstrated the possibility of using x-ray transmission, computed tomography (CT) scanning for soil bulk density analysis in soil. We show that CT can also be used for measuring the water content of soil. We also show that CT can be applied to measure and follow dynamically the motion of water in soil in three dimensions. Furthermore inhomogeneities of water content and motion in soil can be observed with this technique. Using a third-generation CT scanner, several different techniques can be applied, such as differential, real-time, and spatial distribution scanning modes. A linear dependence was demonstrated for the Hounsfield units (HU) used in CT and water content. The use of CT for water content and motion in soil in three dimensions opens new possibilities in this area of investigation.

GE HiSpeed CT/e
Single Slice

Scans of soil samples were obtained with a General Electric CT/T 8800 scanner of the Istituto di Radiologia, Universite di Trieste, Italy. This is a third-generation rotate-rotate CT scanner, which means that the x-ray tube and the detectors rotate simultaneously during the scan. The detector array consists of a 30° arch that contains 523 high-pressure xenon detectors.

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Soil Science Studies

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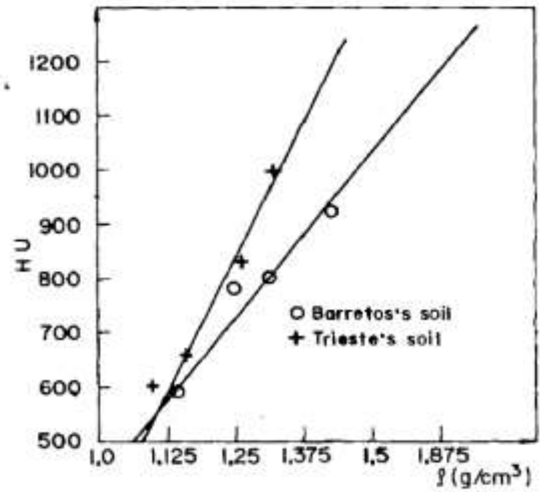

FIG. 1. Linear calibration curve of Hounsfield units (HU) as a function of dry bulk density ρ (mass of dried soil per volume of dried soil). The average value of standard deviation is 32.5 HU.

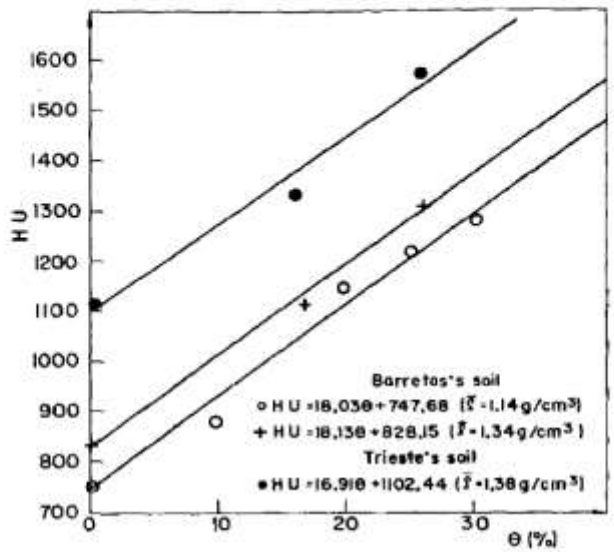

FIG. 2. Linear calibration curve of Hounsfield units (HU) as a function of water content (θ) (volume of water per volume of soil). The average bulk density was obtained from Fig. 1, and the average standard deviation is 63.2 HU.

Device for water distribution

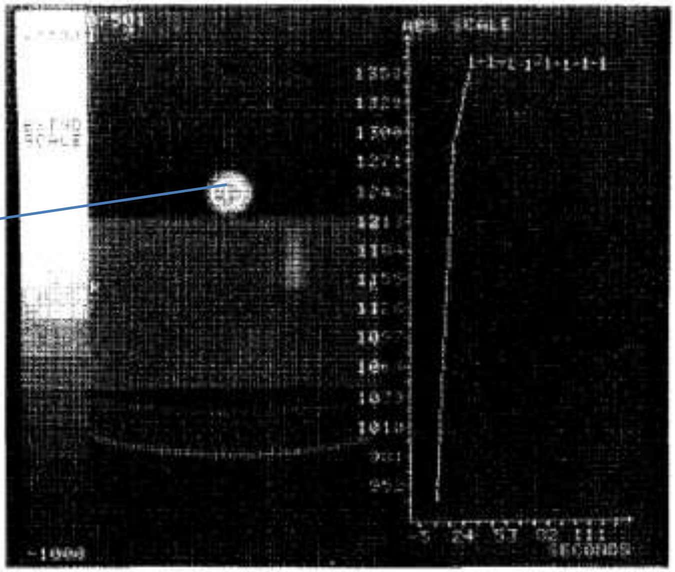

FIG. 3. Dynamic experiment made after introducing water into a horizontal column showing a fixed slice. Ten sequential scans (right-side curve) in HU (absolute scale) as a function of time are shown. The number 1 represents points at the chosen slice.

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S. CRESTANA,[2] S. MASCARENHAS,[3] AND R. S. POZZI-MUCELLI[4]

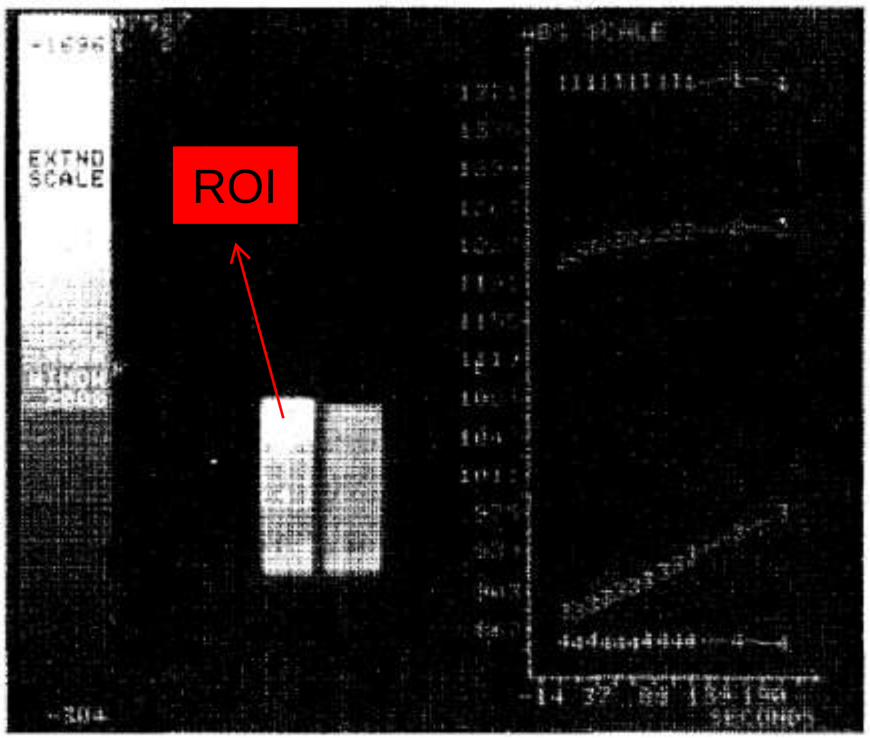

FIG. 4. Spatial and real-time (dynamic) measurement made with a vertical column (left side) at different time intervals. The attenuation was measured in different regions with the ROI (region of interest) boxes indicated by numbers 1, 2, 3, and 4 from top to bottom of the column. On the right side we plotted the variation of water content as a function of time for the different regions.

1. CT scanning can be used to observe and measure quantitatively water content in soil;
2. CT scanning can be used for dynamic (real-time) studies of water motion in soil, including measuring water speeds as high as 1.6 mm/s;
3. CT scanning can be used to obtain information on heterogeneities of water content and 3-D information by using the slicing technique, as discussed here, or by obtaining complete 3-D reconstruction from those data (not presented in this paper);
4. Simultaneous spatial and time distributions of water content can be obtained by the use of appropriate CT techniques, as demonstrated in this work;
5. The slope of linear dependence of Hounsfield units (HU) on water content (θ) changes for different soils, but is independent of bulk density for the same soil. This conclusion shows that HU are a function of both ρ and θ, that is, a CT image of soil is in fact at least a bidimensional function HU (ρ, θ). This very important point has to be taken into account if a quantitative interpretation of soil CT images is required.

Soil Science Studies

SOIL TECHNOLOGY vol. 2, p. 313–321 Cremlingen 1989

USING A COMPUTED TOMOGRAPHY MINISCANNER FOR STUDYING TILLAGE INDUCED SOIL COMPACTION

C.M.P. **Vaz**, S. **Crestana**, S. **Mascarenhas**, P.E. **Cruvinel**, São Carlos
K. **Reichardt**, Piracicaba
R. **Stolf**, Araras

Gamma-ray computed tomography (CT) is used to study thin compacted soil layers, such as millimeter thick "blades" that occur at plowing depth. The technique has the advantage, over the traditional gamma-ray attenuation techniques, of opening the possibility of measuring water contents and bulk-densities of odd-shaped samples. Being a 2- or 3-dimensional technique it is possible to detect small change of bulk-density and soil water content within the sample, even in thin layers of the order of millimeters. Results are reported for thin compacted layers in soil samples collected at the plowing depth from sugar-cane fields in Brazil, which clearly demonstrate the usefulness of this new method for compaction investigations and its quantitative evaluation.

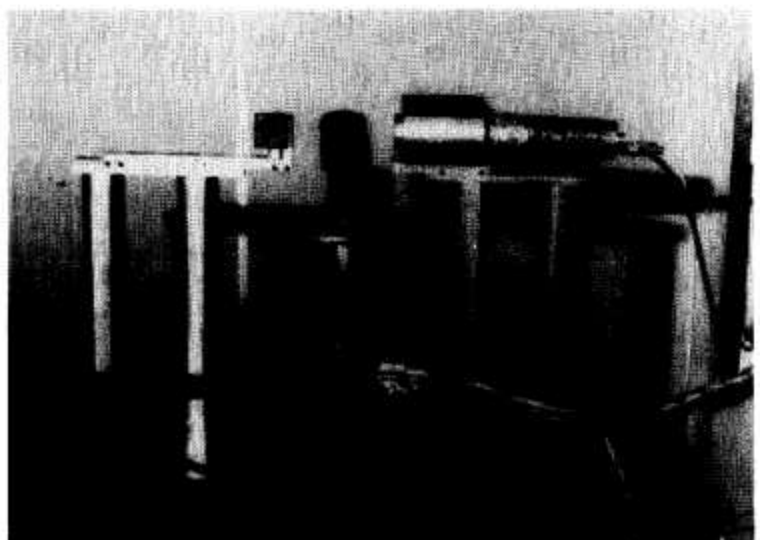

Photo 1: *View of the miniscanner tomography table.*

The gamma-ray CT miniscanner employed in this experiment was built in our laboratory and is dedicated to soil research investigation (CRESTANA et al. 1985, CRUVINEL 1987, CRESTANA et al. 1988 and CESAREO et al. 1988). The computed miniscanner has a 300 mCi ^{241}Am gamma-source, with a peak at 59.6 keV energy and a NaI($T\ell$) scintillation detector associated with a photomultiplier.

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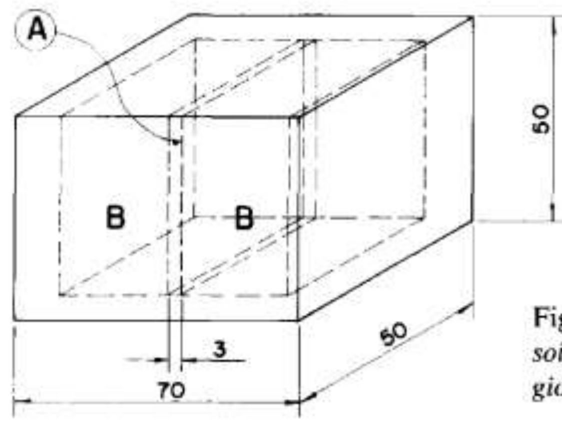


Fig. 1: *Diagram of artificially packed soil samples, with compacted layer (region A) having a width of 3 mm.*

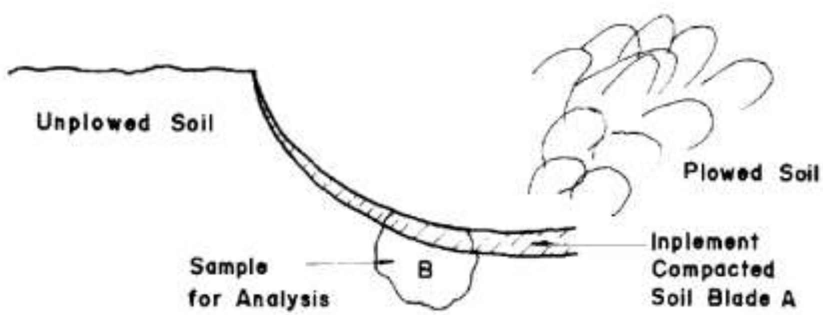
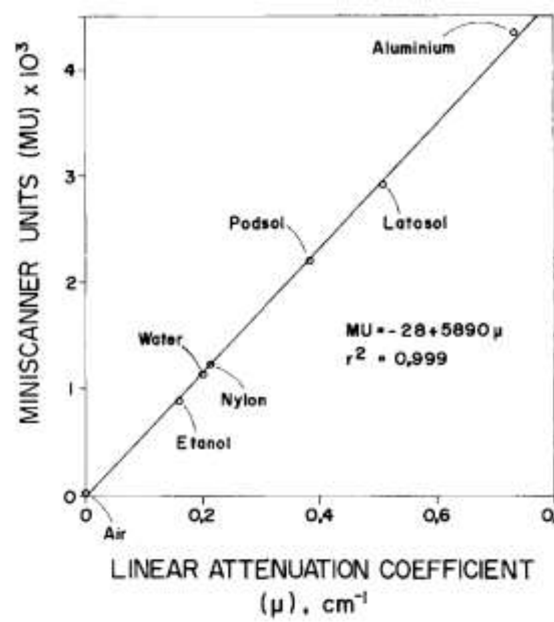


Fig. 2: *Description of the position for collection of soil samples in the field, after deep plowing.*



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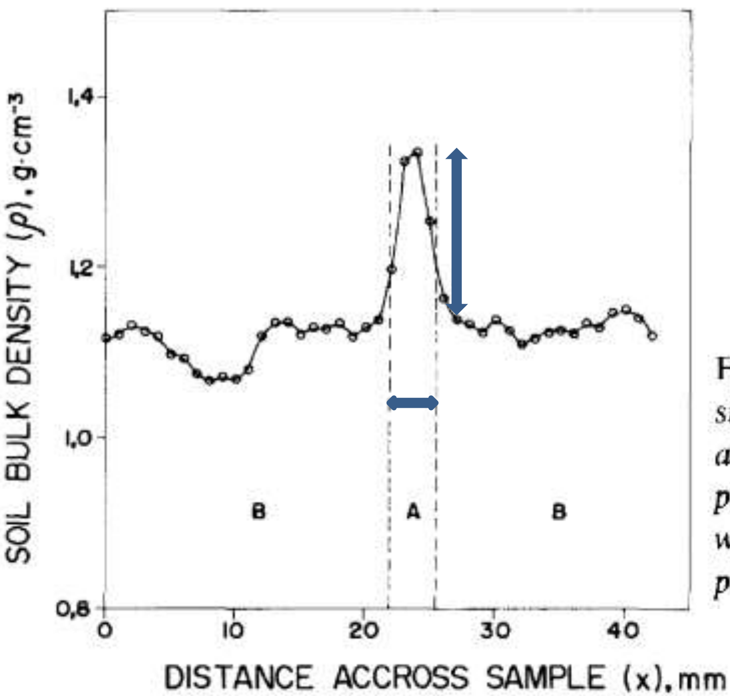

Fig. 6: Soil bulk density distribution of an artificially packed sample as shown in fig.1, with a central compacted layer A.

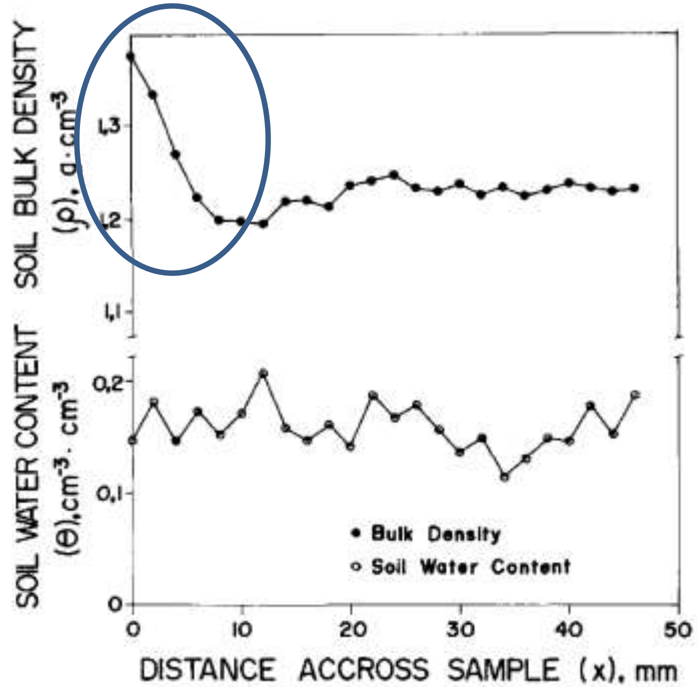

Fig. 7: *Soil bulk density and soil water content distribution of a sample collected at plowing depth, according to sampling procedure shown in fig.2.*

The results of this paper show that the CT technique presents a sufficient resolution to detect thin compacted layers and small changes of bulk density in soil samples of any shape.

Soil Science Studies

IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 39, NO. 5, OCTOBER 1990 745

X- and γ-Rays Computerized Minitomograph Scanner for Soil Science

PAULO ESTEVÃO CRUVINEL, ROBERTO CESAREO, SILVIO CRESTANA, SÉRGIO MASCARENHAS

Abstract—**A computerized tomograph scanner system using X- and γ-rays has been developed for applications in soil science. Previous results were obtained using a miniature X-ray tomograph scanner designed for biomedical analysis [1].**

As a new methodology of instrumentation and in soil research [2], this apparatus has proven to be useful for measuring volumetric water content θ to an accuracy of $\pm 3\%$ and soil bulk density $\rho \pm 2\%$ (in grams/centimeters^3).

The system features translation and rotation scanning modes, a 200-mm effective field of view, signal processing by pulse counting and 1.0-mm spatial resolution. The performance of the system has been demonstrated by experimentally measuring water content and the bulk density of soil samples.

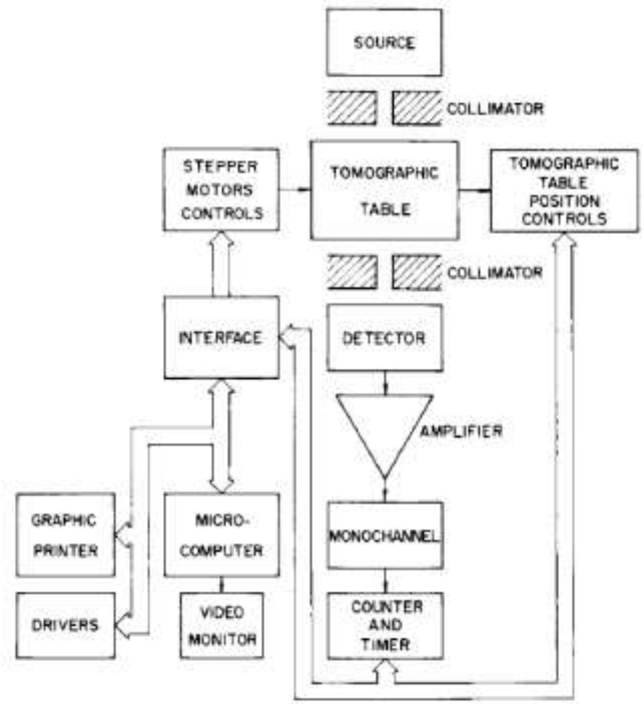

Fig. 3. Block diagram of the minitomograph.

This paper describes a compact low-cost (approximately US$ 50 000) CT-scanner (minitomograph) designed for soil science.

Soil Science Studies

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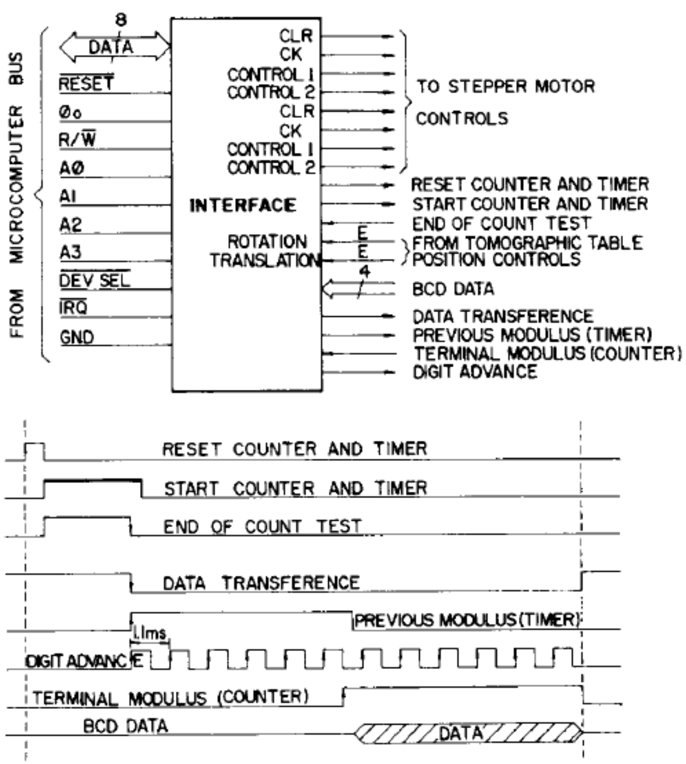

Fig. 6. Schematic diagram and the time sequence of the interface. The amplitude of each step is 5 V.

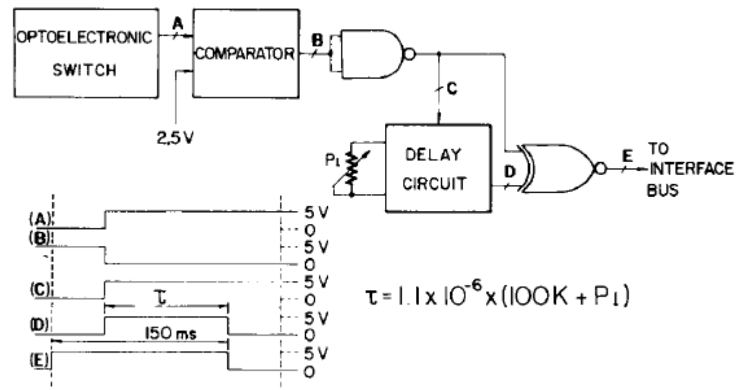

Fig. 5. Schematic diagram and the time sequence of the tomographic table position controls.

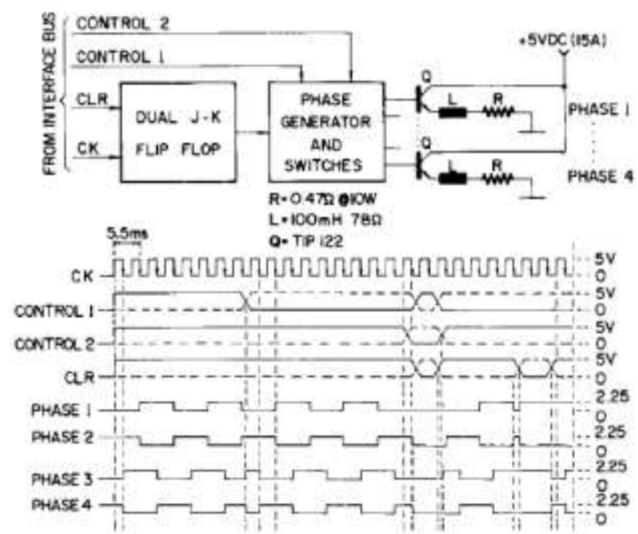

Fig. 4. Schematic diagram and the time sequence of the stepper motor controls.

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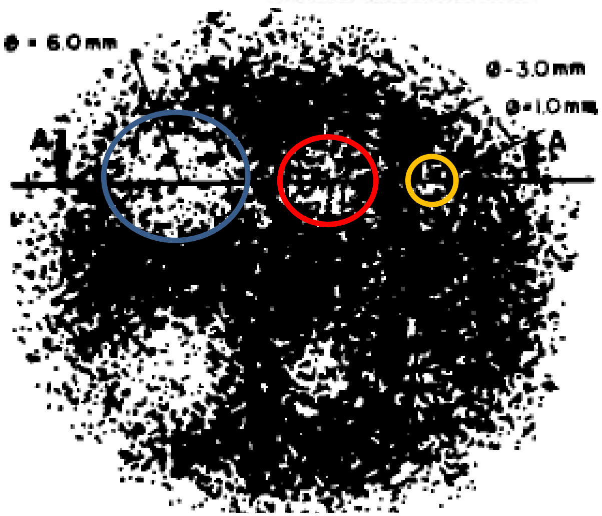

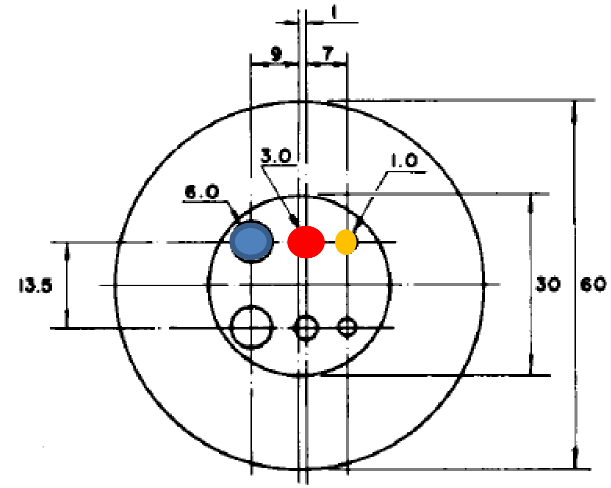

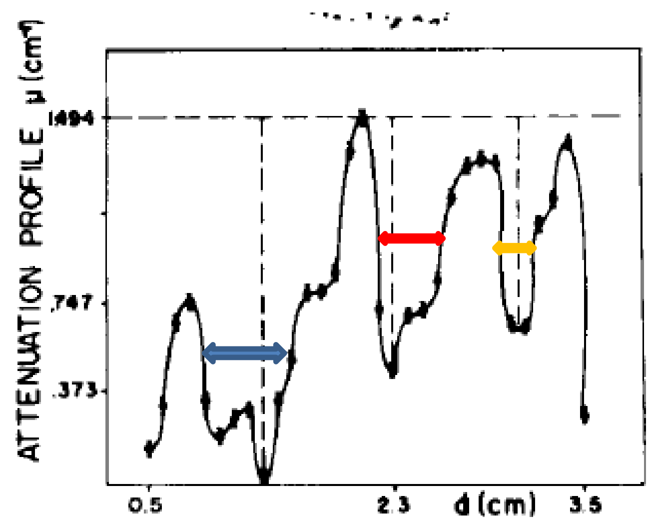

The standard deviation from the mean attenuation did not change significantly with the beam width, however, the counting time was adjusted so that an equal number of photons contributed to each image. For the images generated with the minitomograph system, the best spatial resolution was obtained with a pixel width of 1.0 mm.

Fig. 9. (a) The test object. (b) An image reconstructed on pixel with width of 1.0 mm. (c) An attenuation profile $\mu(cm^{-1})$ versus distance d(cm). The profile relates to line A-A.

Soil Science Studies

ELSEVIER
Soil & Tillage Research 49 (1998) 249–253
Soil & Tillage Research

X-ray microtomography to investigate thin layers of soil clod

A. Macedo*, S. Crestana, C.M.P. Vaz

Embrapa, Agricultural Instrumentation, PO Box 741, 13560 970 São Paulo SP, Brazil

In this paper we present an equipment and a methodology for soil non-invasive investigation at the microscale. We developed a micrometric scale tomograph to work at a resolution of at least 100 μm. A microtomography of 1 mm sand grains and 1 mm grass roots is presented. Inside one of the grains, a crack 110 μm wide per 460 μm long can be observed. Pores of 100 μm can be studied. A microtomography of a little soil clod is shown, in which grains of densities up to 4.5 g cm^{-3} can be seen. Pores ranging from 200 to 800 μm can also be detected in the tomography. As an example of the potential of the method and equipment, soil crusting and sealing can be observed in a natural sample in soil investigations. The image shows three layers of different densities and soil textures. The thicknesses of the layers from top to bottom are, respectively, 1000, 500 and 1700 μm. © 1998 Elsevier Science B.V. All rights reserved.

Soil Science Studies

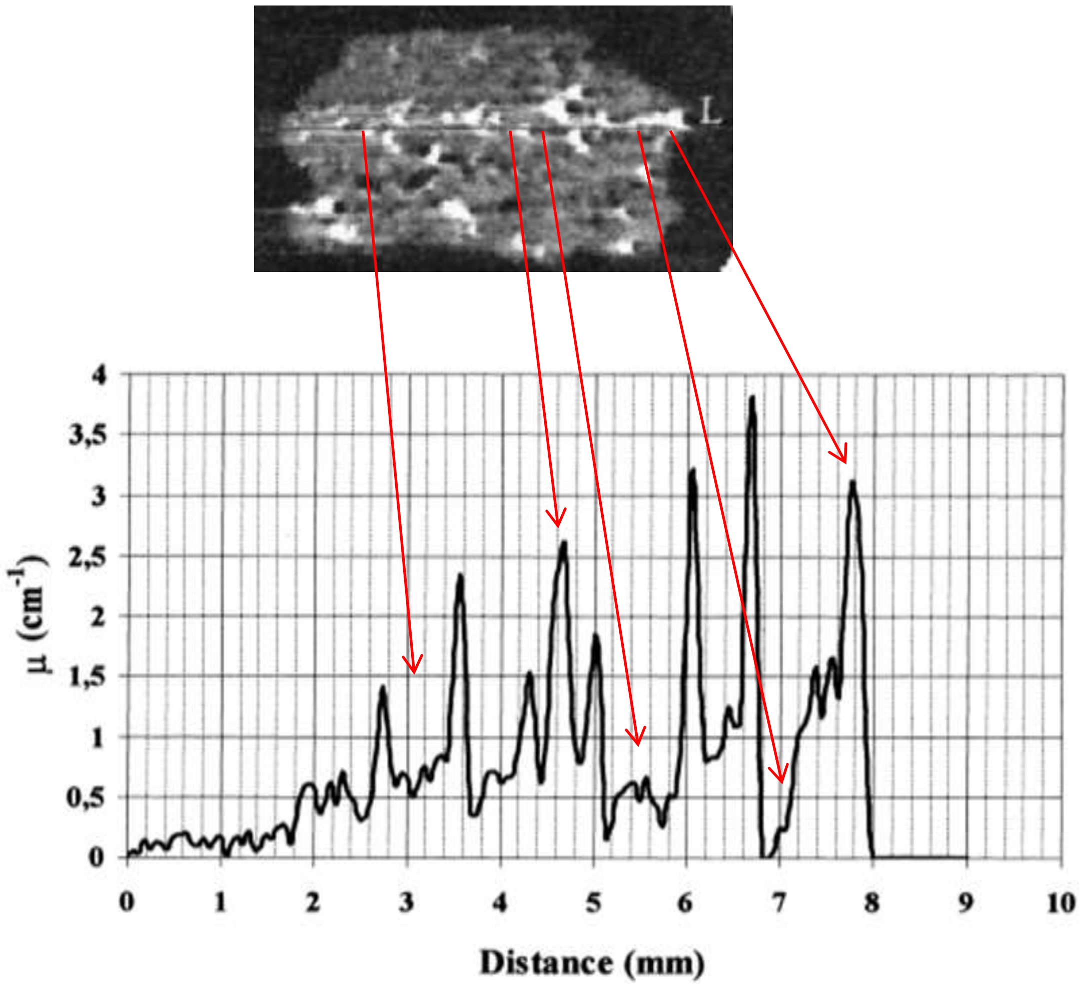

Fig. 3. Variation of tomographic units in transcept L of Fig. 2(a).

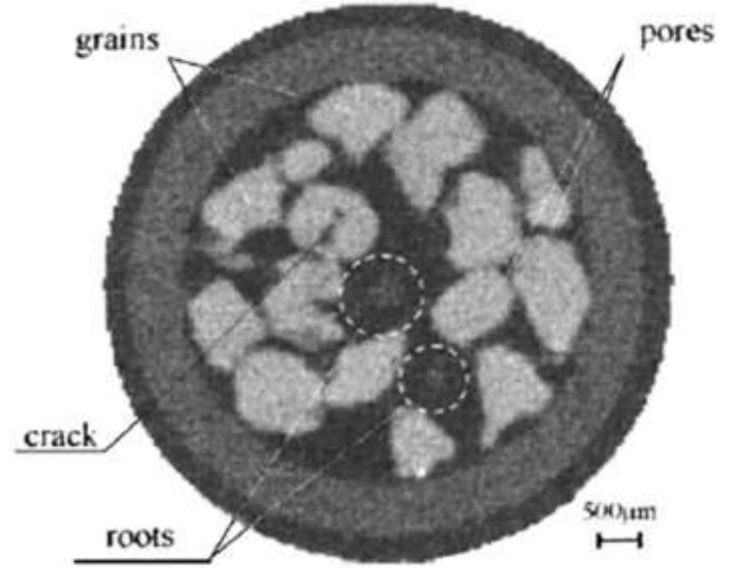

Fig. 1. Microtomography of a sample composed with 1 mm sand grains and 1 mm diameter roots. Pores of 100 μm can be noticed.

Microtomography is an emerging tool that will allow to accomplish new results and insights of opaque and porous systems. It can, for instance, to bring an advance in the study of soil samples presenting surface sealing. The images obtained with this technique showed details that have never before been accomplished with non-invasive techniques.[(b)]

Soil Science Studies

PERGAMON

Applied Radiation and Isotopes 50 (1999) 451–458

Applied Radiation and Isotopes

Neutron computerized tomography in compacted soil

R.T. Lopes*, A.P. Bessa, D. Braz, E.F.O. de Jesus

Laboratório de Instrumentação Nuclear, COPPE/UFRJ, P.O. Box 68509, 21945-970 Rio de Janeiro, Brazil

This work applies the computerized tomography technique using thermal neutron beams for inspection of compacted soil specimens. Several specimens were analysed whose bulk densities vary from 1.61 up to 1.93 g·cm^{-3} and the water content from 7.8 up to 14.8%. The images reconstructed with thermal neutrons are compared with the reconstruction obtained with gamma rays of 316 keV, to demonstrate the sensitivity of the neutron technique. By analysing the reconstructed images it is possible to detect the different water content levels and to identify the soil composition. The macroscopic total cross-section values and the compactation curves obtained using the tomographic images agree with the expected data. © 1999 Elsevier Science Ltd. All rights reserved.

$$I = I_0 \exp(-\Sigma X) \quad (1)$$

when Σ is the macroscopic total cross-section (cm^{-1}).

$$\Sigma = \sum_{i=1}^{n} (\Sigma_i w_i) \quad (2)$$

where w_i is the weighting factor that represents the contribution of the ith element.

$$\Sigma = w_s\Sigma_s + w_a\Sigma_a + w_w\Sigma_w \quad (3)$$

where w_s, w_a and w_w are weighting factors for solid particles, air and water, respectively.

$$\Sigma \cong \Sigma_{ss} + w_w\Sigma_w \quad (4)$$

where Σ_{ss} is the macroscopic total cross-section to dry soil and is given by:

$$\Sigma_{ss} = w_s\Sigma_s + w_{a'}\Sigma_a \quad (5)$$

where $w_{a'}$ is the weighting factor of the air for the dry soil.

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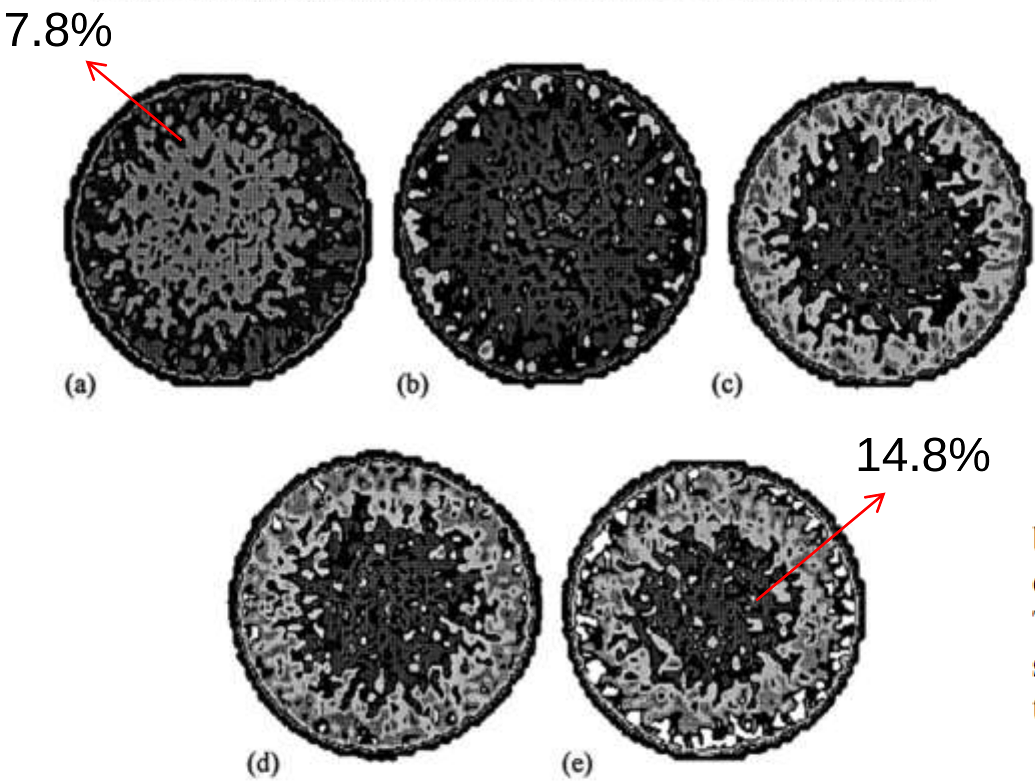

Fig. 4. Reconstructed images of wet compacted soil-1 specimens from thermal neutrons: (a) CP_1, (b) CP_2, (c) CP_3, (d) CP_4 and (e) CP_5.

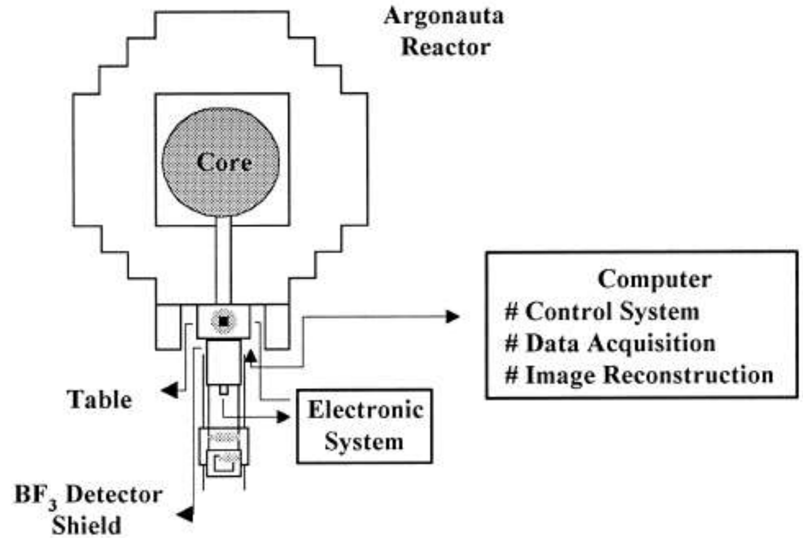

Fig. 1. Diagram of the thermal neutron tomography system.

The neutron CT system used in this experiment was built in our laboratory and has been used in a number of studies, including soil and asphalt investigations. The scanner is a first-generation system with a fixed source-detector arrangement in which specimens are translated and rotated.

Soil Science Studies

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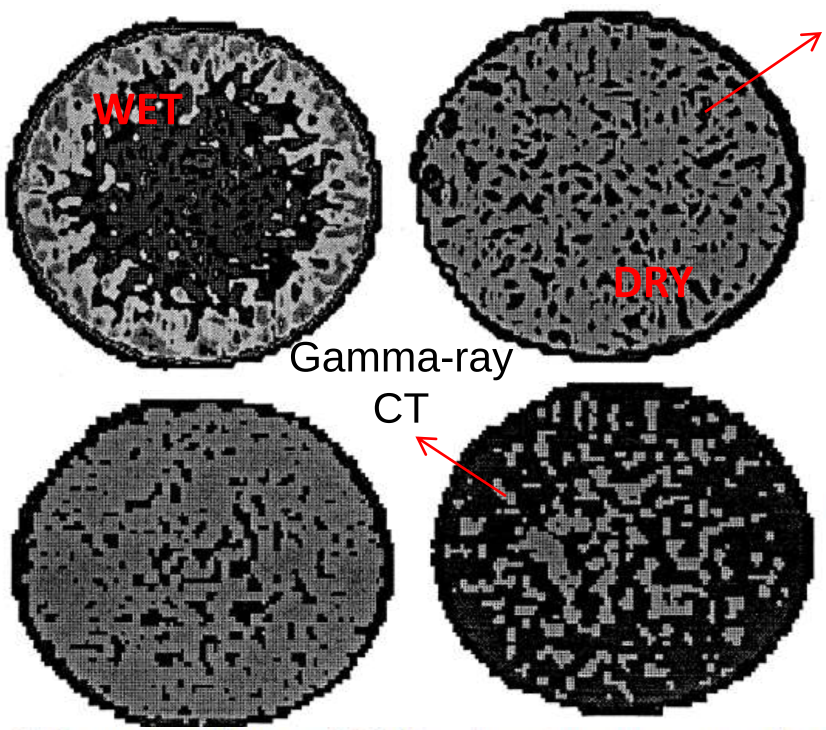

Fig. 9. Reconstructed images of CP_3 from thermal neutrons, wet and dry (upper)
Reconstructed images of CP_3 from gamma radiation, wet and dry (lower).

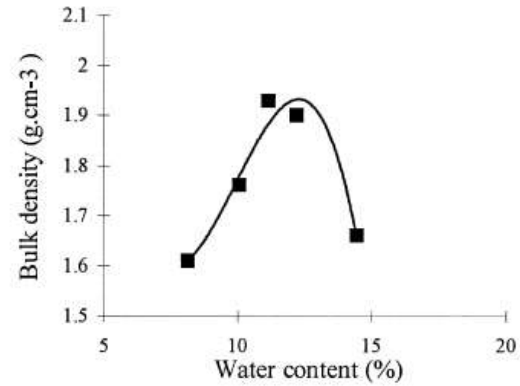

Fig. 7. The compactation curves obtained using the tomographic images.

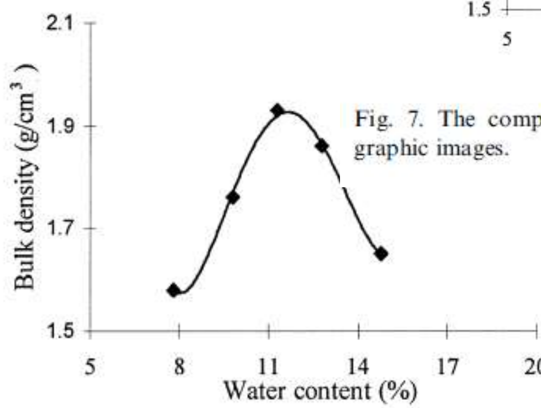

Fig. 8. The compactation curves obtained using the geotechnical methods.

The initial performance evaluation of our thermal neutron tomography system indicates that it is able to distinguish between small differences in the water content. It can be observed in the tomographic images (neutron and gamma) that neutron tomography is more sensitive to the percent water content variation than are the gamma tomographic images.

Soil Science Studies

PERGAMON
Applied Radiation and Isotopes 57 (2002) 375–380
Applied Radiation and Isotopes
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Gamma-ray computed tomography to characterize soil surface sealing

Luiz F. Pires[a,*], Jose R. de Macedo[b], Manoel D. de Souza[c], Osny O.S. Bacchi[a], Klaus Reichardt[a]

[a] Center for Nuclear Energy in Agriculture, USP, C.P. 96, C.E.P. 13.400-970 Piracicaba, SP, Brazil
[b] Embrapa Soils, Rua Jardim Botânico, 1024, C.E.P. 22.260-000 Rio de Janeiro, RJ, Brazil
[c] Embrapa Environment, C.P. 69, C.E.P. 13.820-000 Jaguariúna, SP, Brazil

The application of sewage sludge as a fertilizer on soils may cause compacted surface layers (surface sealing), which can promote changes on soil physical properties. The objective of this work was to study the use of gamma-ray computed tomography, as a diagnostic tool for the evaluation of this sealing process through the measurement of soil bulk density distribution of the soil surface layer of samples subjected to sewage sludge application. Tomographic images were taken with a first generation tomograph with a resolution of 1 mm. The image analysis opened the possibility to obtain soil bulk density profiles and average soil bulk densities of the surface layer and to detect the presence of soil surface sealing. The sealing crust thickness was estimated to be in the range of 2–4 mm. © 2002 Elsevier Science Ltd. All rights reserved.

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Gamma-ray computed tomography to characterize soil surface sealing

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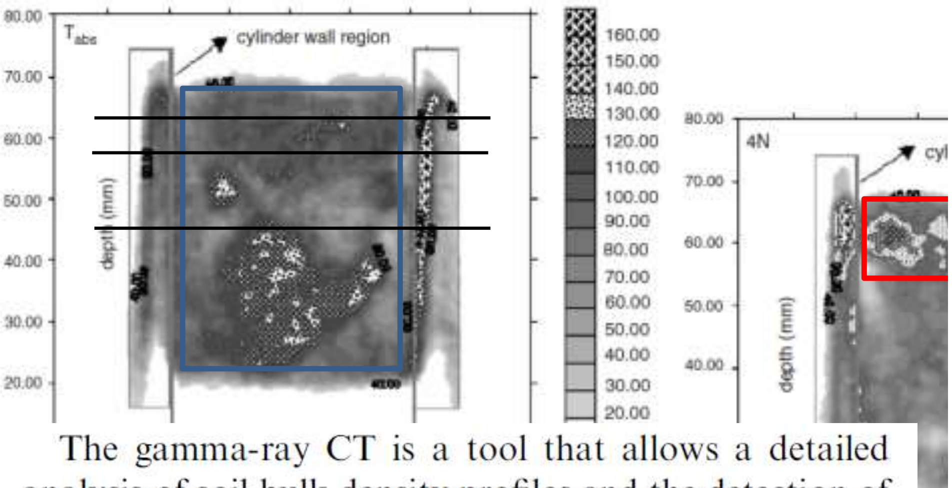
The rates of sludge application were calculated on the basis of dry weigh nitrogen, corresponding to: 10, 40 and 8(



The gamma-ray CT is a tool that allows a detailed analysis of soil bulk density profiles and the detection of very thin compacted or sealed layers.

Using CT it was possible to confirm the occurrence of soil surface sealing due to the sewage sludge application and it was possible to determine average densities and thickness of these layers.

Table 2
Average soil density values of layers presenting sealing (ρ_{crust}) and soil bulk density (ρ_s) for two cylinders (C1 and C2) of soil samples having received different treatments (Tabs and NPK are controls, 1N, 2N, 4N, and 8N, increasing rates of sewage sludge)

Treatment	ρ_{crust} ($g\,cm^{-3}$)	ρ_{crust} ($g\,cm^{-3}$)	ρ_s ($g\,cm^{-3}$)	ρ_s ($g\,cm^{-3}$)
	C1	C2	C1	C2

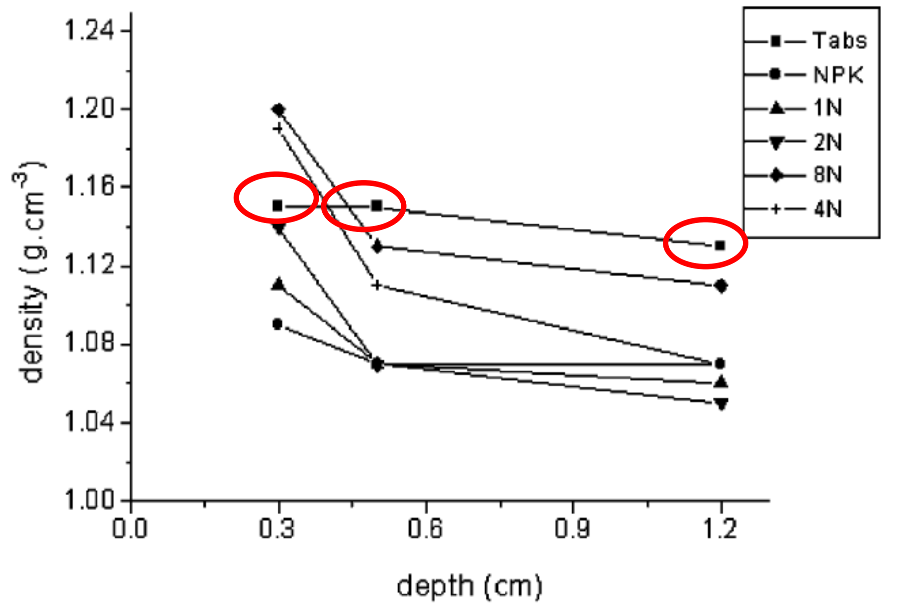


Fig. 10. Gamma-ray transmission analysis of soil density for three depths (3, 5, and 12 mm) for samples of different treatments (Tabs and NPK are controls, 1N, 2N, 4N, and 8N, increasing rates of sewage sludge).

Soil Science Studies

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Nuclear Instruments and Methods in Physics Research A 505 (2003) 502–507
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
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Compton scattering tomography in soil compaction study

F.A. Balogun[a,*], P.E. Cruvinel[b]

[a] Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria
[b] EMBRAPA Instrumentation Centre, Rua XV de Novembro 1452, C. P. 741, 13560-970 São Carlos-SP, Brazil

Compton scattering imaging technique is investigated as a possible tool in soil density distribution mapping for agricultural purposes. In Compton scattering tomography, the number of photons that had been inelastically scattered from a well-defined volume of a sample is employed as a non-destructive technique to display soil density distribution. Images are also shown, of soil samples, at two closely related densities. Good contrast is recorded between the various inserts and their host matrix. Line scans through the images showed good contrast resolution, shape and edge definition. Spatial resolution could be enhanced by the use of a focussing collimator on the detector. This will also serve to increase the solid angle subtended at the detector by the scattering volume, with a possible reduction in counting time at the same precision level.

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A simple scanner employing one detector and one gamma beam was employed in this study. This scanner employs a raster motion for data collection. The scanner is adapted from a minitomographic scanner originally used for transmission-computerised tomography in soil and other agricultural materials [3]. A ^{137}Cs radioactive source emitting photons at energy of 662 keV was employed.

Soil Science Studies

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Nuclear Instruments and Methods in Physics Research A 505 (2003) 502–507
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
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Compton scattering tomography in soil compaction study

F.A. Balogun[a,*], P.E. Cruvinel[b]
[a] Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria
[b] EMBRAPA Instrumentation Centre, Rua XV de Novembro 1452, C. P. 741, 13560-970 São Carlos-SP, Brazil

$$dS = \phi_0 \frac{d\sigma^{KN}}{d\Omega} \rho \frac{N_A z}{A} \, dV \, d\Omega$$

$$dS = k\rho$$

$$dS = \phi_0 \exp\left(\int_{x_1} \mu_1 dx\right) \frac{d\sigma^{KN}}{d\Omega} \rho \times \frac{N_A z \xi t}{A} \exp\left(\int_{x_2} \mu_2 dx\right) d$$

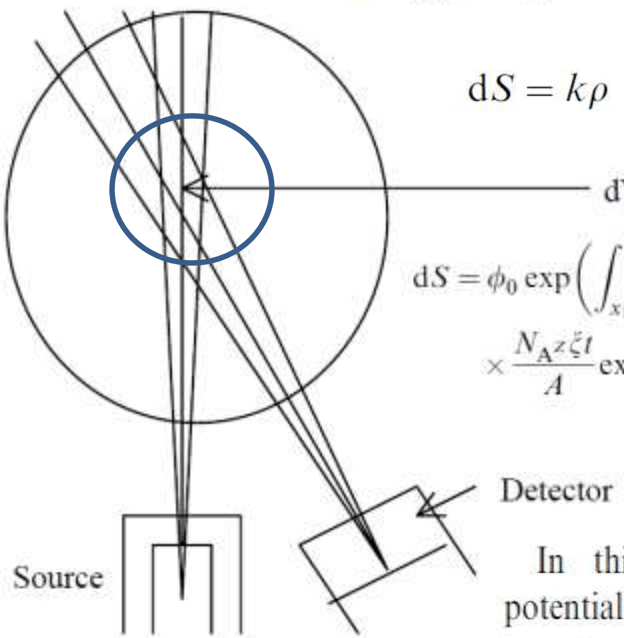

Fig. 1. Scanner.

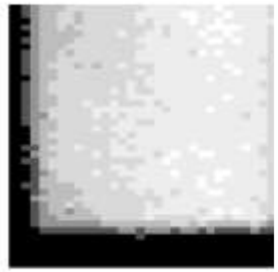

Fig. 2. Showing an ima

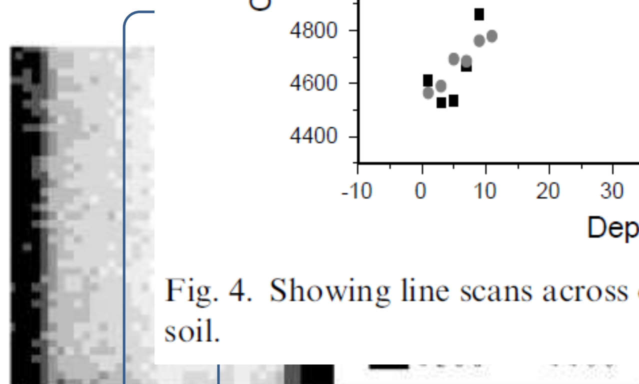

Fig. 3. Showing an image of soil sample with compaction.

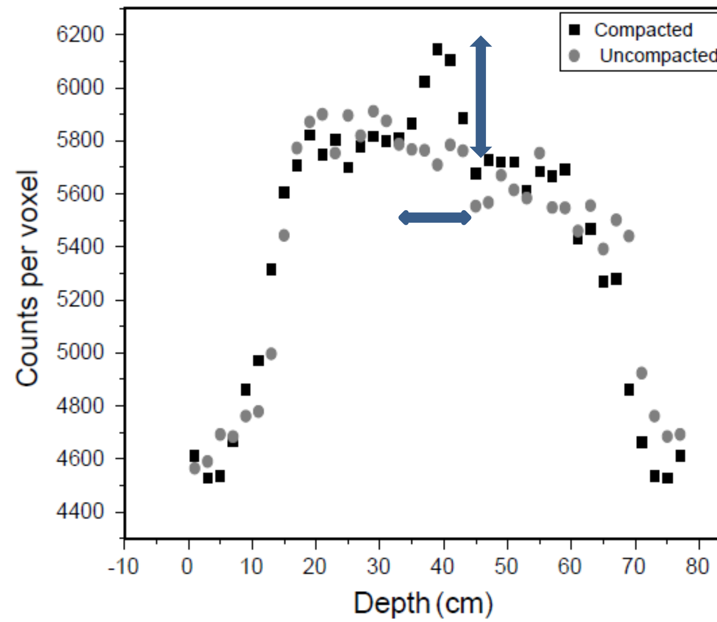

Fig. 4. Showing line scans across compacted and uncompacted soil.

In this work, we have demonstrated the potentials of Compton scattering tomography to reproduce, faithfully, changes in soil density using a laboratory-based inexpensive scanner. Good contrast is recorded between objects of varying densities. Soil samples had been imaged with good contrast between it and it's containing vessel. In a slightly compressed, the technique had proved capable of differentiating between areas of possible compaction.

Soil Science Studies

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Soil & Tillage Research 80 (2005) 115–123

Soil & Tillage Research
www.elsevier.com/locate/still

Evaluation of bulk density of Albaqualf soil under different tillage systems using the volumetric ring and computerized tomography methods

Alceu Pedrotti[a,*], Eloy Antonio Pauletto[b], Silvio Crestana[c], Francisco Sandro Rodrigues Holanda[a], Paulo Estevão Cruvinel[c], Carlos Manoel Pedro Vaz[c]

[a] *Departamento de Engenharia Agronômica (DEA), Universidade Federal de Sergipe (UFS), Campus Universitário, Av. Mal. Rondon, s/n, Jardim Rosa Elze, 49100-000 São Cristovão, SE, Brazil*

[b] *Departamento de Solos, FAEM-Universidade Federal de Pelotas (UFPel), Caixa Postal 354, 96.001-970 Pelotas, RS, Brazil*

[c] *Centro de Instrumentação, CNPDIA-EMBRAPA, Caixa Postal 741, 13560-970 São Carlos, SP, Brazil*

The volumetric ring and the computerized tomography (CT) techniques were applied to study soil bulk density, in order to understand the compaction of an Albaqualf soil (Planosol) of the Rio Grande do Sul State, Southern Brazil (latitude 31°52′00″S and Longitude 52°21′24″W). Among six different tillage systems and crop rotations the greatest soil bulk density was measured for the continuous irrigated rice crop system and the lowest for the no-tillage treatment under rye grass straw. The CT method enabled the measurement of bulk density variations in the soil profile and indicated critical zones not observed by the volumetric ring method that measures only the mean sample soil bulk densities. A meaningful correlation between soil bulk densities measured by both methods was found, although the CT method presented more reliable results in comparison to the volumetric ring method. A 3% variation in bulk density was observed due to method intrinsic errors, probably also correlated to different samples sizes.

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Evaluation of bulk density of Albaqualf soil under different tillage systems using the volumetric ring and computerized tomography methods

Alceu Pedrotti[a,*], Eloy Antonio Pauletto[b], Silvio Crestana[c], Francisco Sandro Rodrigues Holanda[a], Paulo Estevão Cruvinel[c], Carlos Manoel Pedro Vaz[c]

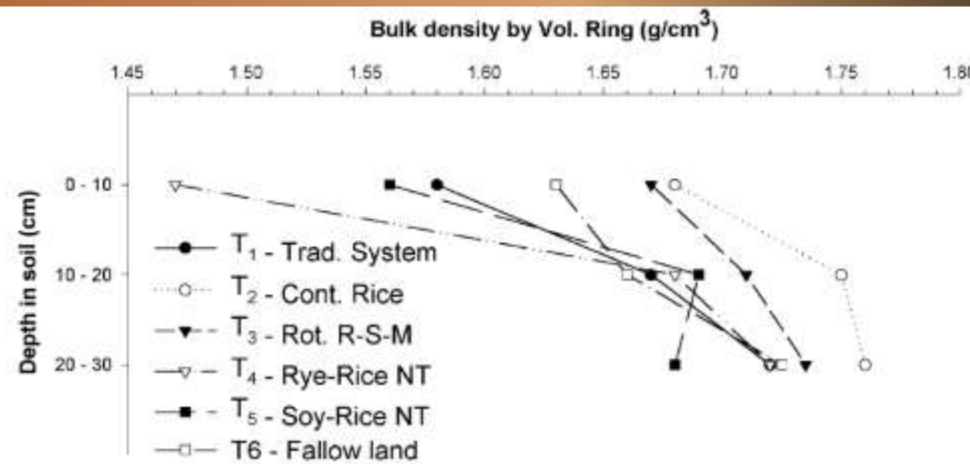

Fig. 1. Bulk density (g/cm³) determined by volumetric ring method by average depth (cm) in different cropping systems.

D_{soil} (CT) = 0.086 (± 0.136) + 0.943 (± 0.081) . D_{soil} (Vol. Ring

R^2 = 0,945 - SD = 0,024 - N = 18 - P = 3,35 X 10^{-9}

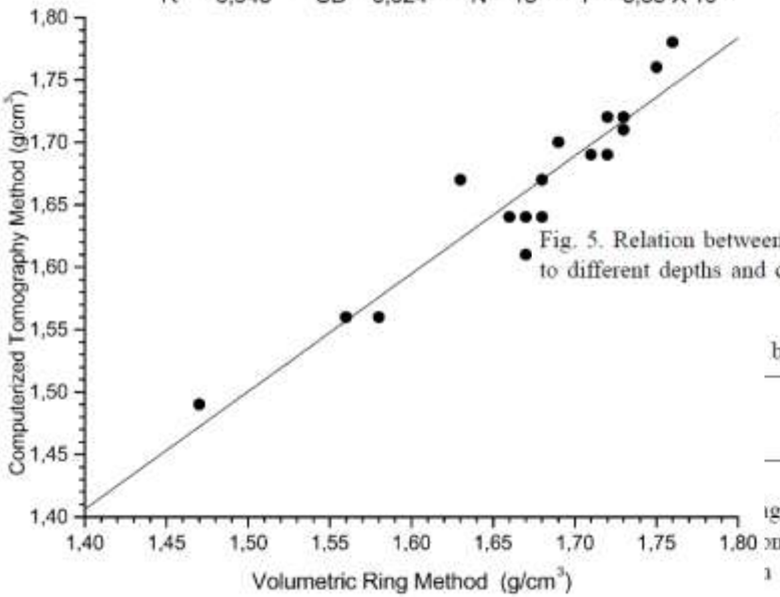

Fig. 5. Relation between the mean values of bulk density (g/cm³), determined by volumetric ring and computerized tomography methods, to different depths and cropping systems.

by volumetric ring method, in the studied treatments (mean of 27 replications)

	Depth (cm)			Mean value
	0–10	10–20	20–30	
	1.58 bcB	1.67 bA	1.72 abA	1.65
ige	1.68 aB	1.75 aA	1.76 aA	1.73
on	1.67 aA	1.71 abA	1.73 abA	1.70
ı	1.47 dB	1.68 abA	1.72 abA	1.63
[illegible]	1.56 cB	1.69 abA	1.68 bA	1.65
T_6: fallow land	1.63 abB	1.66 bB	1.73 abA	1.67

Mean values followed by the same lower case letter within the column and capital letter within the line are not significantly different by Duncan's multiple range test at the 0.05 level ($P < 0.05$).

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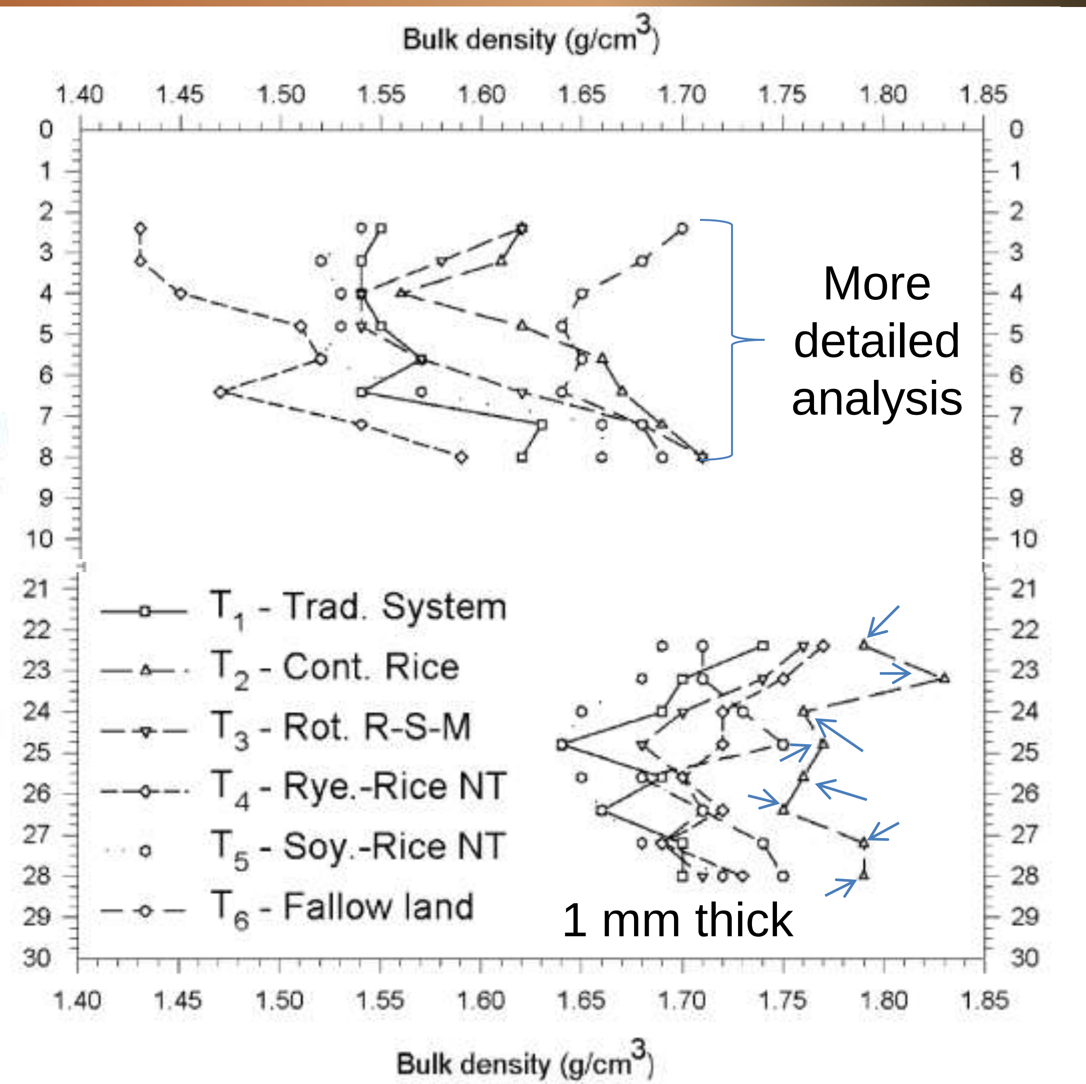
- The computerized tomography method provided a more detailed and precise soil bulk density determination thus allowing more accurate identification of soil compacted layers.
- A highly significant correlation among the values of soil bulk density was obtained through the studied methods, indicating that the data obtained by tomography are very reliable when compared to those from the volumetric ring.



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Application of γ-ray computed tomography to evaluate the radius of influence of soil solution extractors and tensiometers

Luiz F. Pires *, Robson C.J. Arthur, Osny O.S. Bacchi, Klaus Reichardt

Center for Nuclear Energy in Agriculture, University of Sao Paulo, Soil Physics Laboratory, CP 96, CEP 13.400-970 Piracicaba, SP, Brazil

Tensiometers and soil solution extractors are tools commonly used in irrigated agriculture and in studies of soil solute movement. The matric potential (Ψ_m) measured through tensiometers represents the energy by which water is retained by soil matrix. A relevant aspect that has to be taken into account while evaluating any instrument based on the use of sensors, like the porous cup of tensiometers, is the interference of the sensor on the property that is being measured. Information related to the range of influence of the sensor, its response power and its operation become very important when one is looking for precise results. The objective of this study was to evaluate the region of influence of tensiometer and solution extractor porous cups used in soil physical measurements. A first-generation γ-ray scanner was used having a ^{241}Am γ-ray source and a 7.62×7.62 cm NaI(Tl) scintillation crystal detector coupled to a photomultiplier tube. Image analysis and tomographic unit distributions could successfully be used for visualizing soil water content changes around the porous cup and for verifying its range of influence. The results show that computed tomography technique is a valuable tool because it makes it possible to provide an insight about the soil water content spatial distributions around the porous cup of tensiometers and solution extractors. The way that soil water content and matric potential are affected by these sensors was shown by this study.

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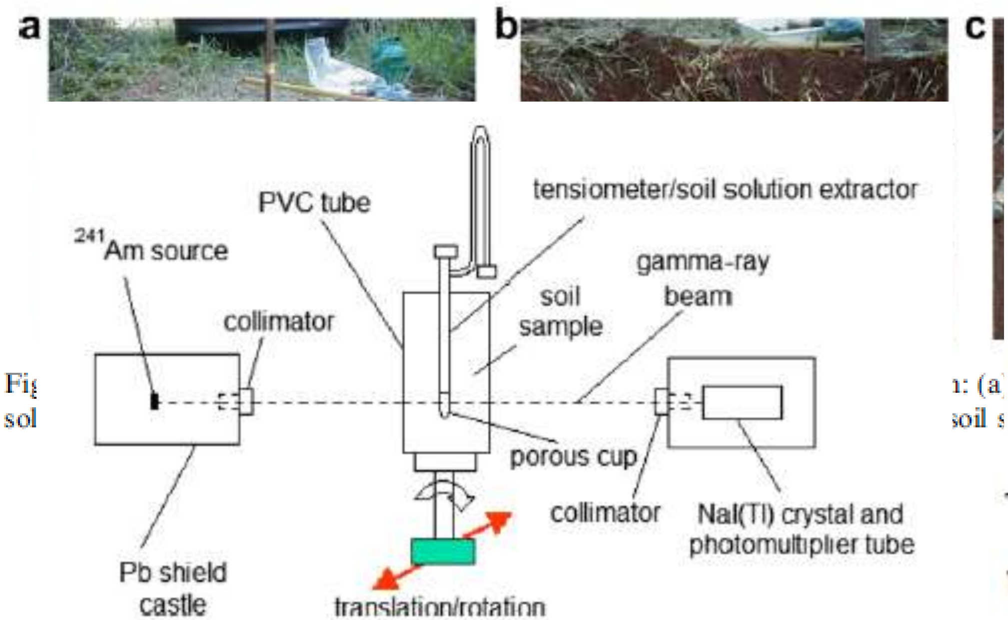

Fig. 2. Scheme of the γ-ray computed tomography system to evaluate soil water content variations of samples with tensiometers and solution extractors.

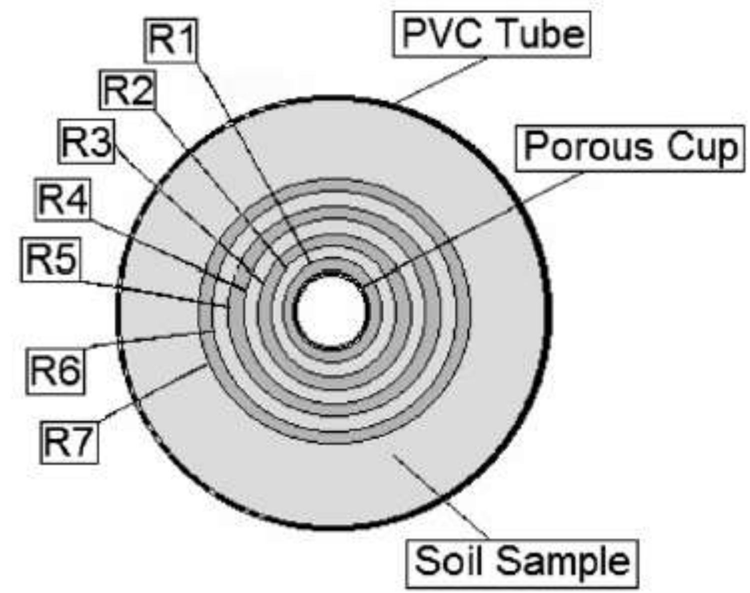

Fig. 3. Designations of the circular sample regions used in the analysis of the images. Images of horizontal cross-sections have been acquired, which makes it possible to analyze soil water content variations in two dimensions.

$$\mathrm{TU_B} = \alpha(\mu_s\rho_s + \mu_w\rho_w\theta) \quad (1)$$

$$\mathrm{TU_A} = \alpha(\mu_s\rho_s + \mu_w\rho_w\theta) \quad (2)$$

$$\Delta\theta = \frac{\Delta \mathrm{TU}}{\alpha\mu_w} \quad (3)$$

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It was demonstrated by the results that the γ-ray CT technique is a valuable tool because it makes it possible to analyze in a non destructive way soil water content changes for soils with different textures.

Using 2D tomographic images and TU values it was possible to evaluate, for two different Brazilian soil types, the influence of tensiometers and solution extractors in water distribution during its use. These results are very important because they provide an insight about how the tensiometers and solution extractors can affect the physical properties analyzed, e.g. soil water content and matric potential.

Table 1

Circle areas (C_A), radius (R), mean tomographic unit (TU) values, and mean soil water contents (θ) of samples with tensiometers before and after equilibrium

Soil	R (cm)	C_A (cm^2)	TU_B	TU_A	ΔTU	Δθ (%)
Geric Ferralsol	0.5	0.8	211^A	281^B	70	37.05^A
	1.0	3.1	269^A	316^B	47	24.73^B
	1.5	7.1	311^A	339^B	28	14.52^C
	2.0	12.6	329^A	349^B	20	10.63^D
	2.5	19.6	344^A	356^B	12	6.42^E
	3.0	28.3	354^A	361^A	7	$3.68^{E,F}$
	3.5	38.5	364^A	368^A	4	2.00^F
Rhodic Ferralsol	0.5	0.8	209^A	270^B	61	32.31^A
	1.0	3.1	272^A	308^B	36	18.94^B
	1.5	7.1	321^A	342^B	21	10.95^C
	2.0	12.6	345^A	357^B	12	$6.53^{C,D}$
	2.5	19.6	359^A	367^A	8	4.42^D
	3.0	28.3	369^A	373^A	4	1.89^D
	3.5	38.5	376^A	379^A	3	1.37^D

R represents the values of the radius presented in Fig. 3; TU_B and TU_A are the tomographic unit values before and after equilibrium; ΔTU and Δθ are the tomographic unit and the soil water content variations, respectively. The numbers followed by the same letters at fourth and fifth columns are not significantly different according to the t-Student test at $\alpha = 0.05$. The numbers followed by the same letters at last column are not significantly different according to the Tukey test at $\alpha = 0.05$.

Soil Science Studies

Ciênc. Agrotec., Lavras, v.38, n.5, p.445-460, set./out., 2014

SPATIAL VARIABILITY OF PORES IN OXIDIC LATOSOL UNDER A CONSERVATION MANAGEMENT SYSTEM WITH DIFFERENT GYPSIUM DOSES

Carla Eloize Carducci[1], Geraldo César Oliveira[2], Nilton Curi[2], Diogo Francisco Rossoni[3], Alisson Lucrécio Costa[2], Richard Jonh Heck[4]

Soil structure is modify when subjected to the agricultural process, i.e., a new spatial organization of the pores system is formed, with relation to the physical quality of it. Thus the aim of this work was to visualize and quantify, through X-ray CT scan, the pores distribution in an oxidic Latosol submitted to a conservation management system with different gypsum doses. Three random trenches were dug lengthwise along the plant row in a very clayey gibbsitic dystrophic Red Latosol, subjected to the following gypsum levels: G0: absence of gypsum; G7: 7 Mg ha-1 and G28: 28 Mg ha-1 of additional gypsum, applied to the surface of the plant row. Undisturbed soil samples were collected in plexiglass tubes at depths of 0.20-0.34, 0.80-0.94 and 1.50-1.64 m after six years of coffee cultivation for quantification of 3D pores obtained by X-ray CT scan. The spatial variability of the soil structure was evaluated by semivariograms generated by 3D images in grayscale. Distribution of the detectable pore diameter was conducted by data mining. Statistical analyzes employed packages 'geoR' to semivariogram and 'randomForest' for data mining in R language. A greater spatial continuity of the pores occurred in the G7 at the three depths. The combined effects of the management system promoted a greater spatial variability of the soil structure in the G28 treatment. Based on geostatistical analyses, it can be infer that the adoption of the system under study promoted changes in the pore network in all directions (X, Y and Z), however with better pores continuity in the vertical direction(Z).

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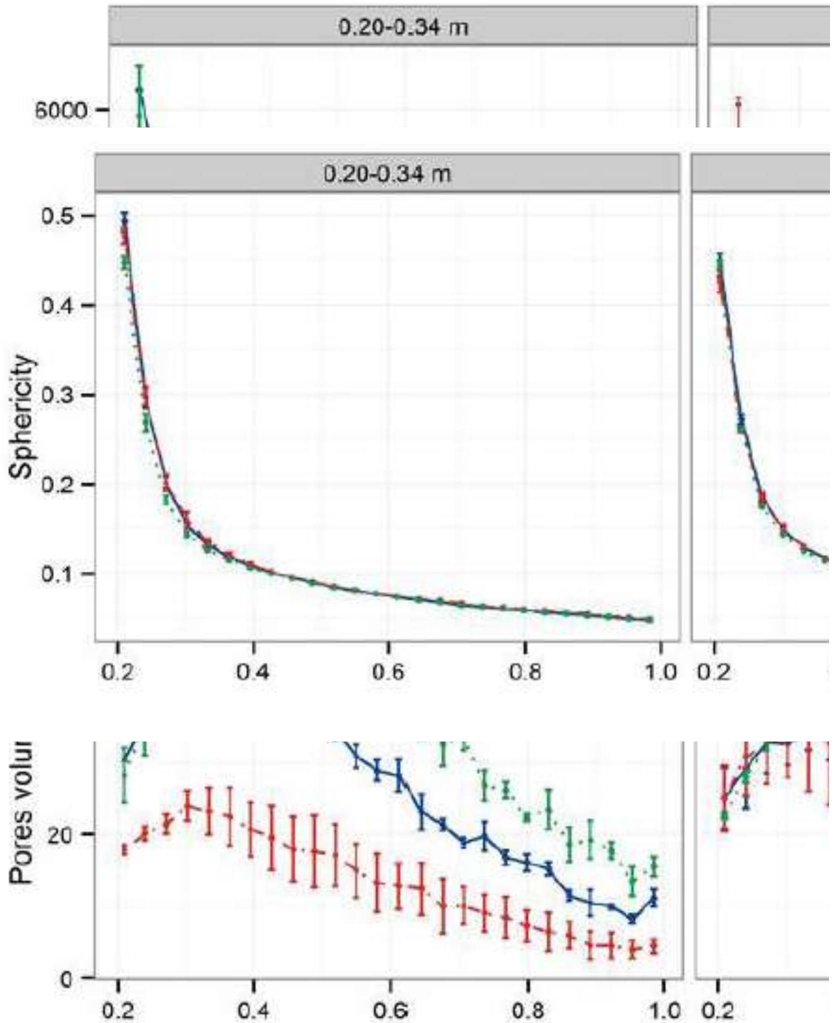

A greater spatial continuity of pores was detected in G7 at the depths evaluated.

A highly homogeneous distribution of the visible pores volume in each class occurred in G7 especially at 0.20-0.34m depth.

The largest pore number and volume were detected in G28 in the 0.20-0.34m depth, as well as the greatest spatial variability of soil structure, promoted by the effect of combined practices of the management system.

Based on geostatistical analyses, it can be inferred that the adoption of the management system under study promoted changes in the pore network in all directions (X, Y and Z), but with better pores continuity in the vertical direction (Z).

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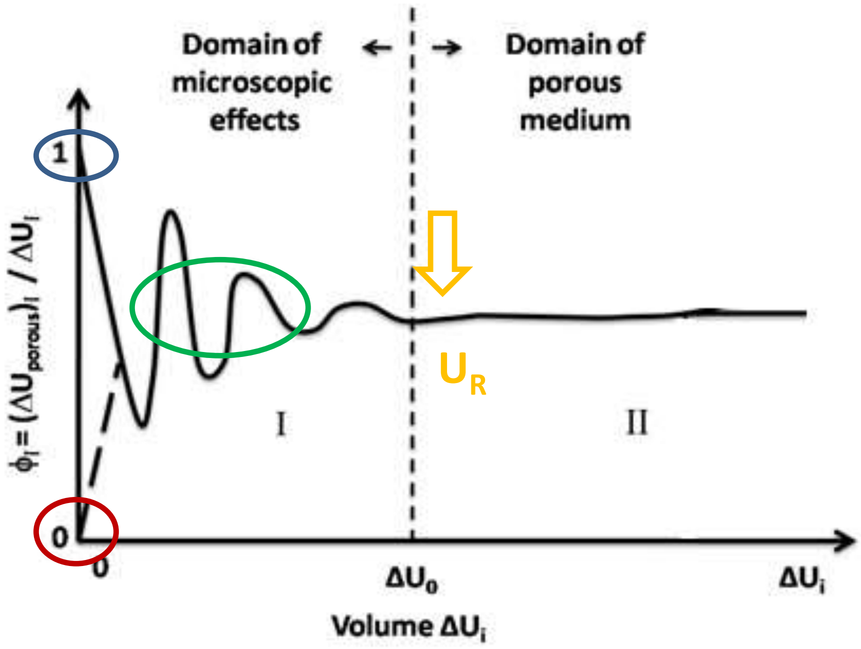
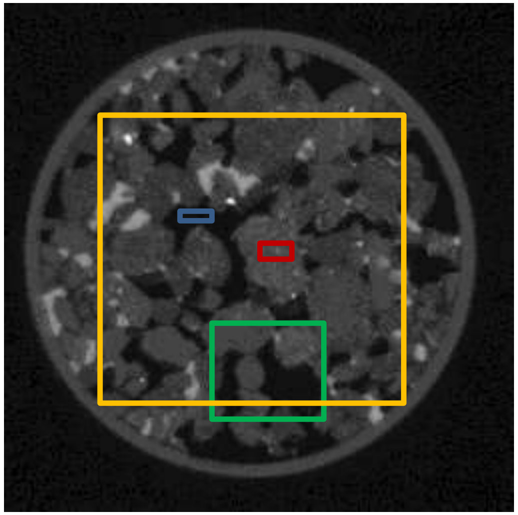
- **Representative elementary size (RES)**





Representative elementary volume (REV, ΔU_0) of the porosity (ϕ). ΔU_i represents any volume in the porous media. Representative elementary area (REA) is defined from the REV concept and presents similar behavior. Adapted from Bear (1972).

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Representative elementary area (REA) in soil bulk density measurements through gamma ray computed tomography

Jaqueline A.R. Borges, Luiz F. Pires *

Laboratory of Soil Physics and Environmental Sciences, Department of Physics, State University of Ponta Grossa (UEPG), CEP 84.030-900, Ponta Grossa, PR, Brazil

Gamma ray computed tomography (CT) has recently become a useful tool for non-invasive characterization of soil physical parameters. Such technique is interesting because it can be used, for instance, in measurements of representative elementary area or volume (REA or REV) of soil samples used to assess soil physical properties. Soil scientists are aware that a sample has to be of a certain size in order to represent certain physical property of that soil in the field. In this study, CT was used to measure REA of samples of a Brazilian soil of clay texture. The objective of using this technique was to verify the minimum volume of soil to be collected for bulk density measurements (ρ_s) through the paraffin sealed clod method (PSC). Results revealed that samples with volumes from 50 to 100 cm^3, with minimum cross section 640.1 mm^2 are enough to produce representative ρ_s values.

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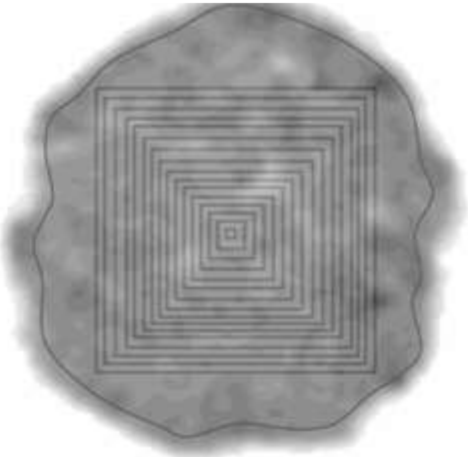
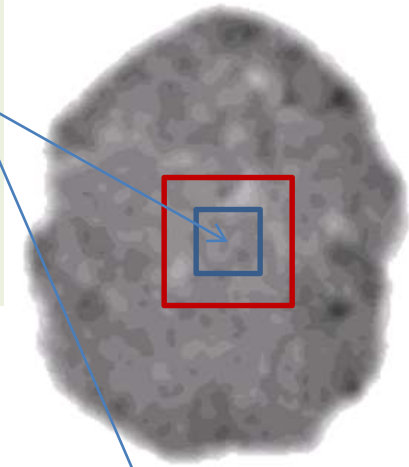


Area	Size (mm^2)	Area	Size (mm^2)
01	1.2	09	349.7
02	10.9	10	436.8
03	30.3	11	533.6
04	59.3	12	640.1
05	98.0	13	756.3
06	146.4	14	882.1
07	204.5	15	1017.6
08	272.3	16	1162.8

Soil bulk density was evaluated for each of the quadrangular area and also the FA



1.66	1.67	1.68	1.74	1.80	1.80
1.71	1.60	1.70	1.68	1.73	1.80
1.71	1.62	1.65	1.74	1.69	1.70
1.64	1.67	1.60	1.59	1.70	1.81
1.66	1.74	1.74	1.72	1.74	1.82
1.64	1.72	1.69	1.75	1.73	1.75
1.66	1.64	1.66	1.62	1.64	1.73
1.65	1.63	1.66	1.69	1.54	1.65
1.62	1.64	1.65	1.65	1.60	1.62
1.65	1.63	1.66	1.69	1.54	1.65
1.66	1.62	1.73	1.67	1.66	1.67
1.81	1.67	1.69	1.62	1.70	1.67
1.87	1.61	1.65	1.69	1.75	1.76
1.82	1.63	1.69	1.76	1.73	1.72
1.83	1.69	1.75	1.83	1.76	1.76
1.78	1.65	1.69	1.79	1.71	1.72

Schematic drawn of the area construction on tomographic images and respective areas adopted for the REA definition. From the data matrix which generates the tomographic image, it is possible to select the soil bulk density (ρ_s) data matrix and from it lines or columns to quantify the ρ_s variations along the sample.

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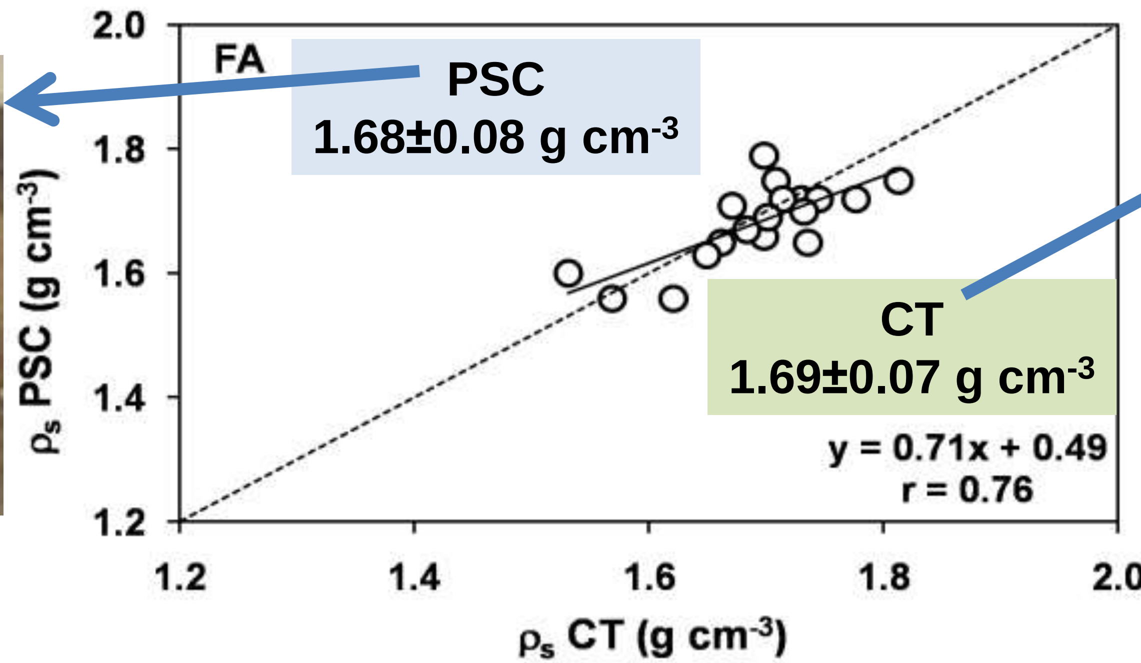
Representative elementary area (REA) in soil bulk density measurements through gamma ray computed tomography

Jaqueline A.R. Borges, Luiz F. Pires *

Laboratory of Soil Physics and Environmental Sciences, Department of Physics, State University of Ponta Grossa (UEPG), CEP 84.030-900, Ponta Grossa, PR, Brazil

- CT vs PSC (n=18)



Correlation between soil bulk density (ρ_s) values obtained through CT and PSC methods. CT results were obtained considering FA .

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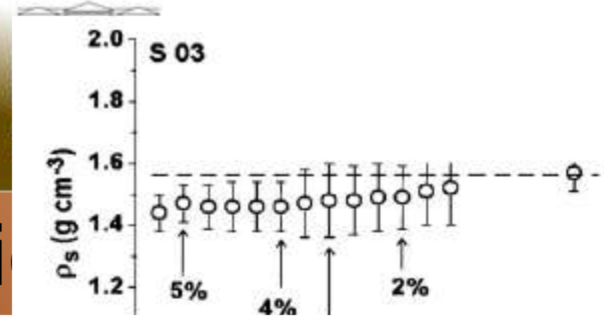

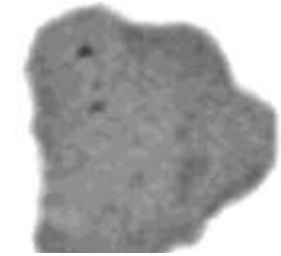

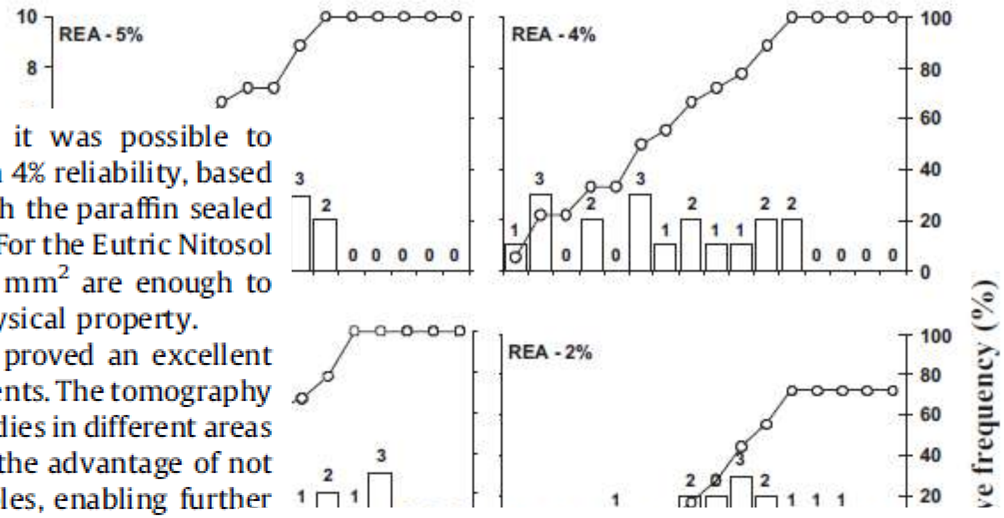

Using 2D images of soil clod samples, it was possible to determine the REA for ρ_s measurements with 4% reliability, based on the ρ_s CV measurements obtained through the paraffin sealed clod method, adopted as a standard method. For the Eutric Nitosol of clay texture, cross section areas of 640.1 mm^2 are enough to provide representative values of this soil physical property.

The first generation gamma ray CT was proved an excellent technique to determine REA for ρ_s measurements. The tomography enables qualitative as well as quantitative studies in different areas selected in the tomographic image, and has the advantage of not changing the physical structure of the samples, enabling further analyses using the same samples.

Fig. 2. Schematic drawn o
respective areas adopted f
to the free area (FA). Dark

i. Relative deviation
of the other areas
ii. That at least three
values, using the

Table 2
Areas in which each sample reached the representative elementary area (REA) for the soil bulk density (ρ_s).

S	REA	S	REA	S	REA
01	06	07	12	13	07
02	02	08	02	14	08
03	06	09	11	15	10
04	12	10	11	16	06
05	02	11	01	17	04
06	08	12	04	18	09

Fig. 5. Soil bulk dens
(arrows), when thos
clod (PSC) method. T
represents the free area.

Fig. 6. Frequency and cumulative frequency (%) of soil bulk density (ρ_s) data for the different areas selected in samples and for the different criteria used for the representative elementary area (REA) definition.

Soil Science Studies

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Volume 2014, Article ID 584871, 9 pages
http://dx.doi.org/10.1155/2014/584871

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Research Article

Representative Elementary Length to Measure Soil Mass

J. A. R. Borges, L. F. Pires, and J. C. Costa

Laboratory of Soil Physics and Environmental Sciences, Department of Physics, State University of Ponta Grossa, Avenue Carlos Cavalcanti 4748, 84030-900 Ponta Grossa, PR, Brazil

With increasing demand for better yield in agricultural areas, soil physical property representative measurements are more and more essential. Nuclear techniques such as computerized tomography (CT) and gamma-ray attenuation (GAT) have been widely employed with this purpose. The soil mass attenuation coefficient (μ_s) is an important parameter for CT and GAT analysis. When experimentally determined (μ_{es}), the use of suitable sized samples enable to evaluate it precisely, as well as to reduce measurement time and costs. This study investigated the representative elementary length (REL) of sandy and clayey soils for μ_{es} measurements. Two radioactive sources were employed (^{241}Am and ^{137}Cs), three collimators (2–4 mm diameters), and 14 thickness (x) samples (2–15 cm). Results indicated ideal thickness intervals of 12–15 and 2–4 cm for the sources ^{137}Cs and ^{241}Am, respectively. The application of such results in representative elementary area (REA) evaluations in clayey soil clods via CT indicated that μ_{es} average values obtained for $x > 4$ cm and source ^{241}Am might induce to the use of samples which are not large enough for soil bulk density evaluations (ρ_s). As a consequence, ρ_s might be under- or overestimated, generating inaccurate conclusions about the physical quality of the soil under study.

Soil Science Studies

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http://dx.doi.org/10.1155/2014/584871

Research Article

Representative E
Attenuation Coef

J. A. R. Borges, L. F. Pi

Soil	SiO
Sandy	62.8
Clayey	44.1

(i) relative difference between the μ_{es} value of each sample thickness used and its average value ($x < 10$ and $x \geq 10$ cm) not superior to 2%;

(ii) at least three consecutive thicknesses cannot differ from each other regarding μ_{es} values, employing the variation criterion in item (i).

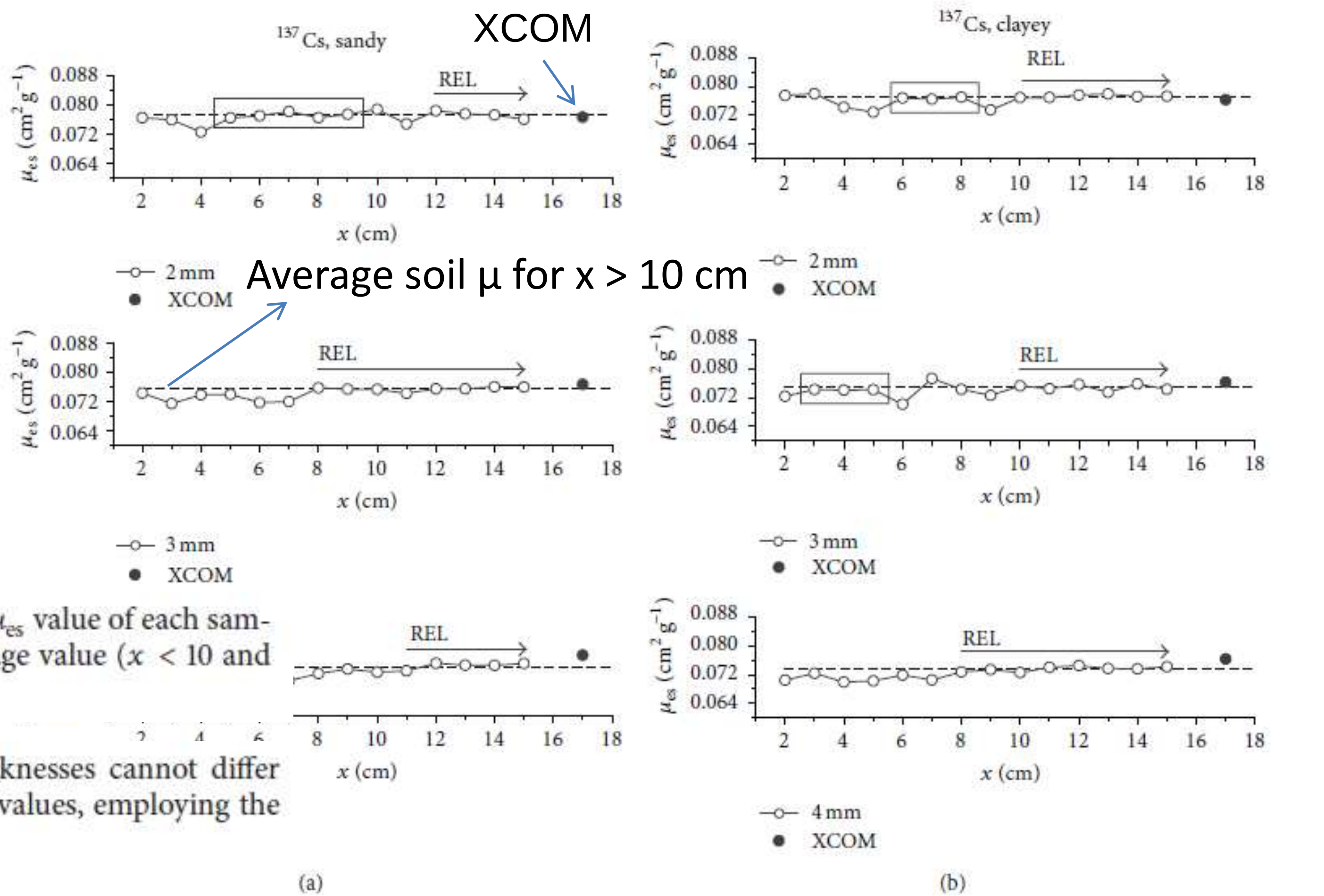

FIGURE 1: Soil experimental mass attenuation coefficient (μ_{es}) and representative elementary length (REL). Results were obtained for different sample thicknesses (x), types of soil ((a), (b)), and collimators for the ^{137}Cs source. The dashed line corresponds to the average of μ_{es} values for the sample thickness $x \geq 10$ cm. The solid symbol corresponds to the theoretical value obtained via XCOM.

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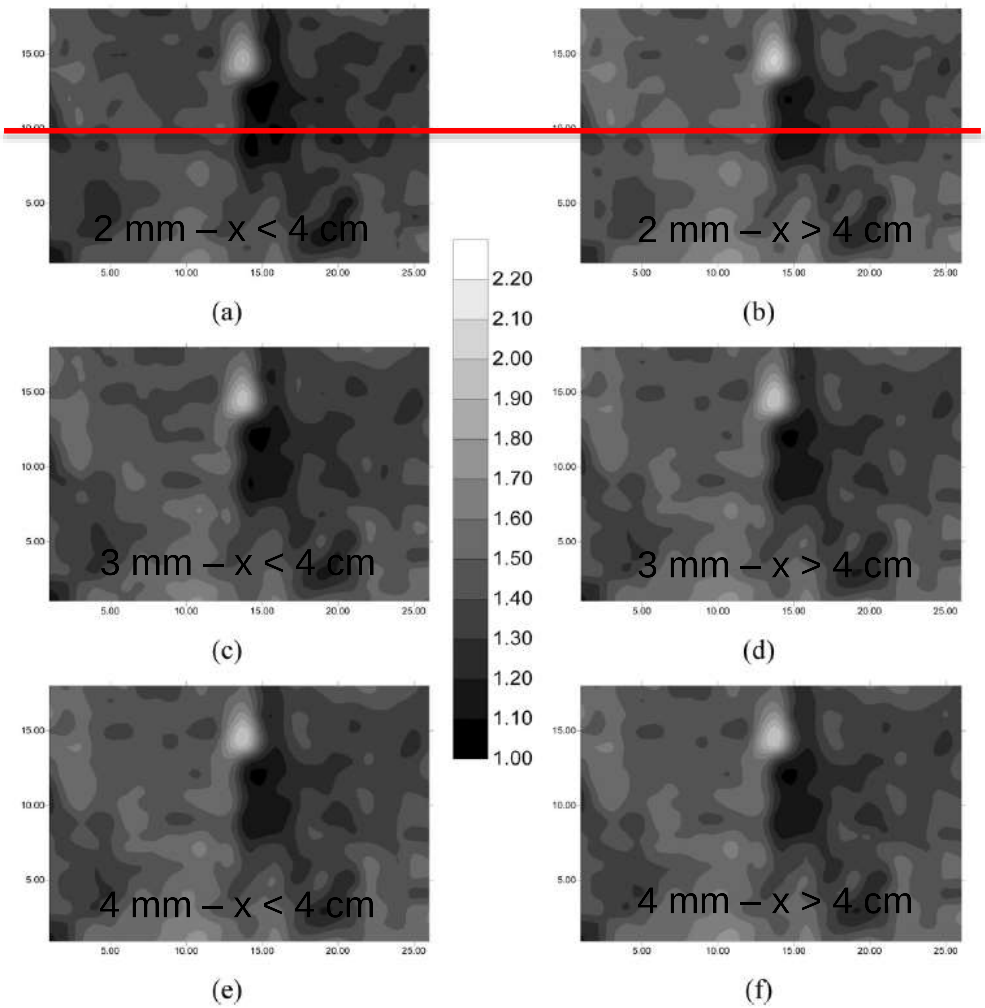

Fig. 7. Tomographic images representing soil bulk density (ρ_s) maps with the ^{241}Am source for the clayey soil. The μ value of the soil used to generate the ρ_s maps refers to the average between μ values for the thicknesses <4 cm ($kx < 1.5$) and ≥4 cm ($kx > 1.5$). The gray scale presents ρ_s values. (a) 2 mm collimator and $x < 4$ cm; (b) 2 mm collimator and $x \geq 4$ cm; (c) 3 mm collimator and $x < 4$ cm; (d) 3 mm collimator and $x \geq 4$ cm; (e) 4 mm collimator and $x < 4$ cm; (f) 4 mm collimator and $x \geq 4$ cm.

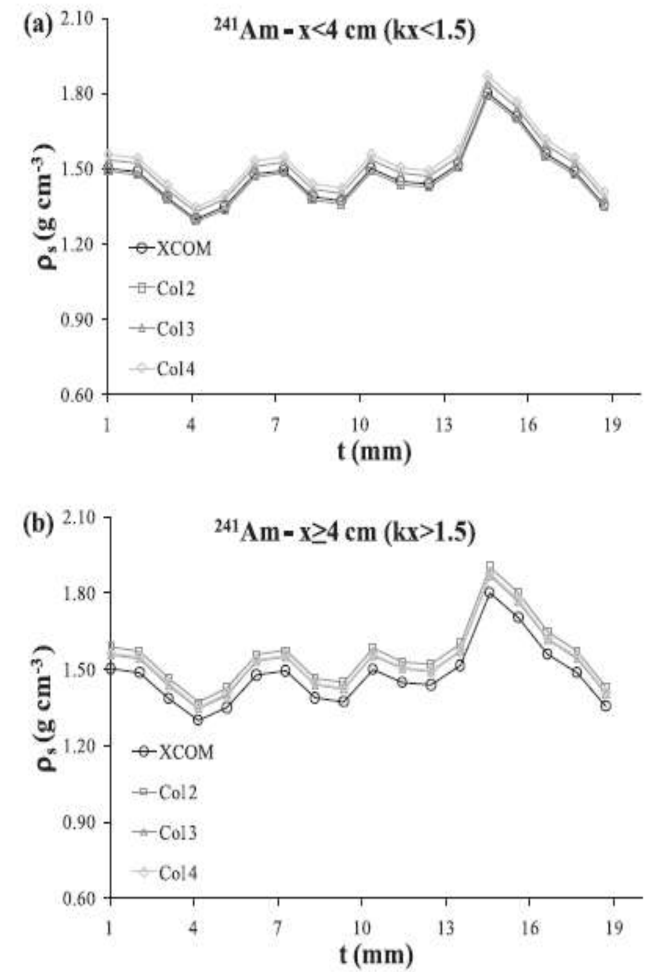

Fig. 8. Variations in clayey soil bulk density (ρ_s) (^{241}Am) as a function of differences in collimator size and sample thickness. (a) $x < 4$ cm ($kx < 1.5$); (b) $x \geq 4$ cm ($kx > 1.5$). The x-axis presents values along the line selected in the ρ_s matrix.

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Review

Twenty-five years of computed tomography in soil physics: A literature review of the Brazilian contribution

Luiz F. Pires[a,*], Jaqueline A.R. Borges[a], Osny O.S. Bacchi[b], Klaus Reichardt[b]

Soil & Tillage Research 145 (2015) 171–180
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Gypsum effects on the spatial distribution of coffee roots and the pores system in oxidic Brazilian Latosol

C.E. Carducci[a,*], G.C. Oliveira[b,1], N. Curi[b,1], R.J. Heck[c,2], D.F. Rossoni[d,3], T.S. de Carvalho[b,e,1,4], A.L. Costa[b,1]

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Protocolo 101.13 – 04/04/2013 • Aprovado em 25/10/2013

Spatial distribution of coffee roots and pores of two Latosols under conservationist management

Carla E. Carducci[1], Geraldo C. de Oliveira[2], José M. Lima[3], Diogo F. Rossoni[4], Alisson L. da Costa[5] & Larissa M. Oliveira[6]

Other Recent Studies

Eng. Agric., Jaboticabal, v.34, n.6, p. 1162-1174, nov./dez. 2014

APPLICATION OF X-RAY COMPUTED TOMOGRAPHY IN THE EVALUATION OF SOIL POROSITY IN SOIL MANAGEMENT SYSTEMS

JOSÉ M. G. BERALDO[1], FRANCISCO DE A. SCANNAVINO JUNIOR[2], PAULO E. CRUVINEL[3]

Computers and Electronics in Agriculture 111 (2015) 151–163

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Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

A model for soil computed tomography based on volumetric reconstruction, Wiener filtering and parallel processing

M.F.L. Pereira [a,b,c,*], P.E. Cruvinel [b,c]

Soil & Tillage Research 152 (2015) 74–84

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Soil & Tillage Research

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Soil hydrology & structure

Representative elementary area for soil bulk density measurements of samples collected in volumetric rings by CT image analyses

Talita R. Ferreira *, Jaqueline A.R. Borges, Luiz F. Pires

Other Recent Studies

Geoderma 213 (2014) 512–520

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Geoderma

journal homepage: www.elsevier.com/locate/geoderma

The effect of wetting and drying cycles on soil chemical composition and their impact on bulk density evaluation: An analysis by using XCOM data and gamma-ray computed tomography

Luiz F. Pires *, Luís V. Prandel, Sérgio C. Saab

Applied Radiation and Isotopes 92 (2014) 37–45

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Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Porosity distribution by computed tomography and its importance to characterize soil clod samples

Luiz F. Pires *, André M. Brinatti, Sérgio C. Saab, Fabio A.M. Cássaro

Soil & Tillage Research 129 (2013) 23–31

Contents lists available at SciVerse ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

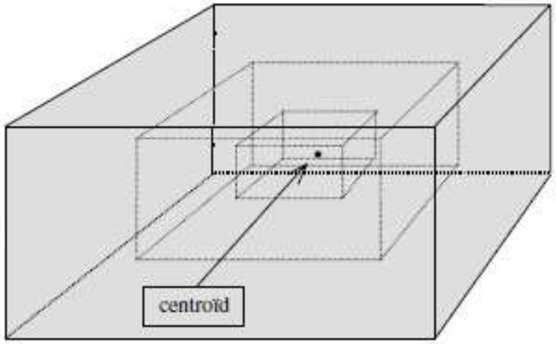
Soil bulk density evaluated by gamma-ray attenuation: Analysis of system geometry

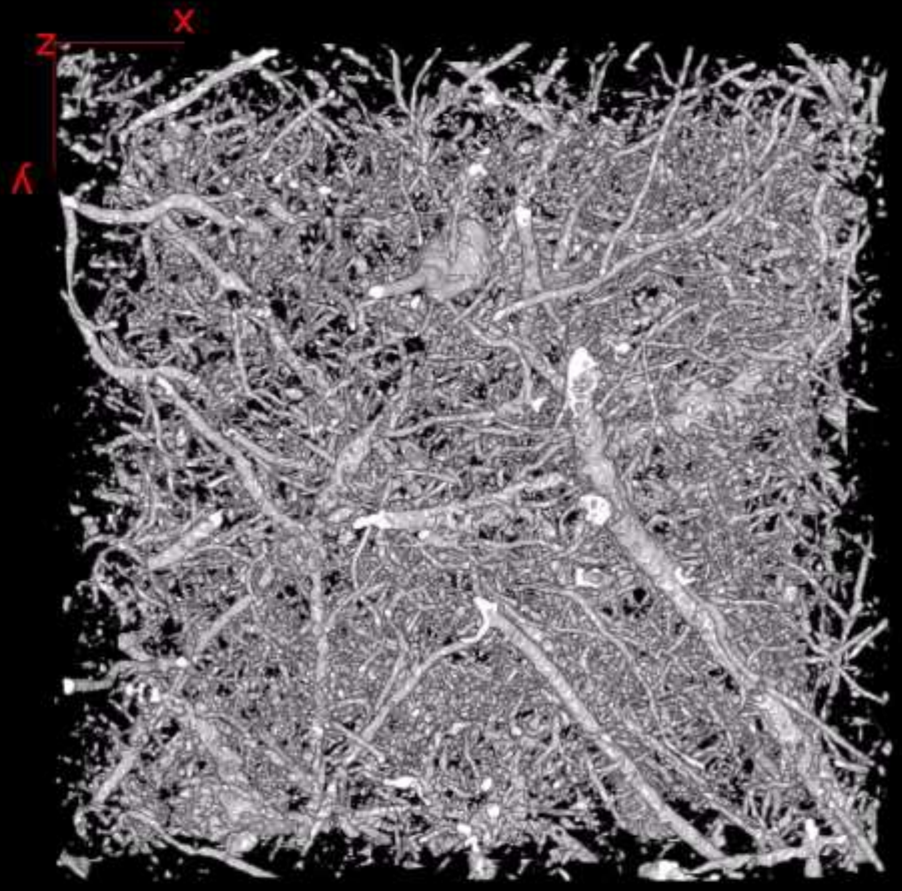
J.C. Costa, J.A.R. Borges, L.F. Pires *

Laboratory of Soil Physics and Environmental Sciences, Department of Physics, State University of Ponta Grossa, UEPG, CEP 84030-900, Ponta Grossa, PR, Brazil

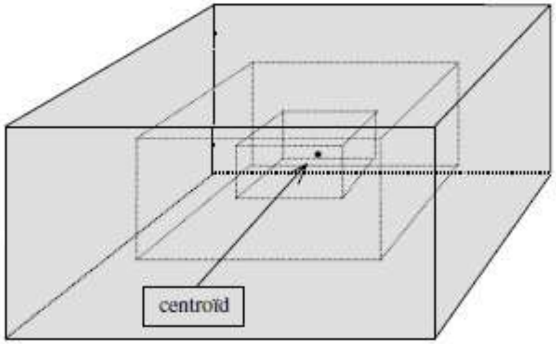
FUTURE WORKS

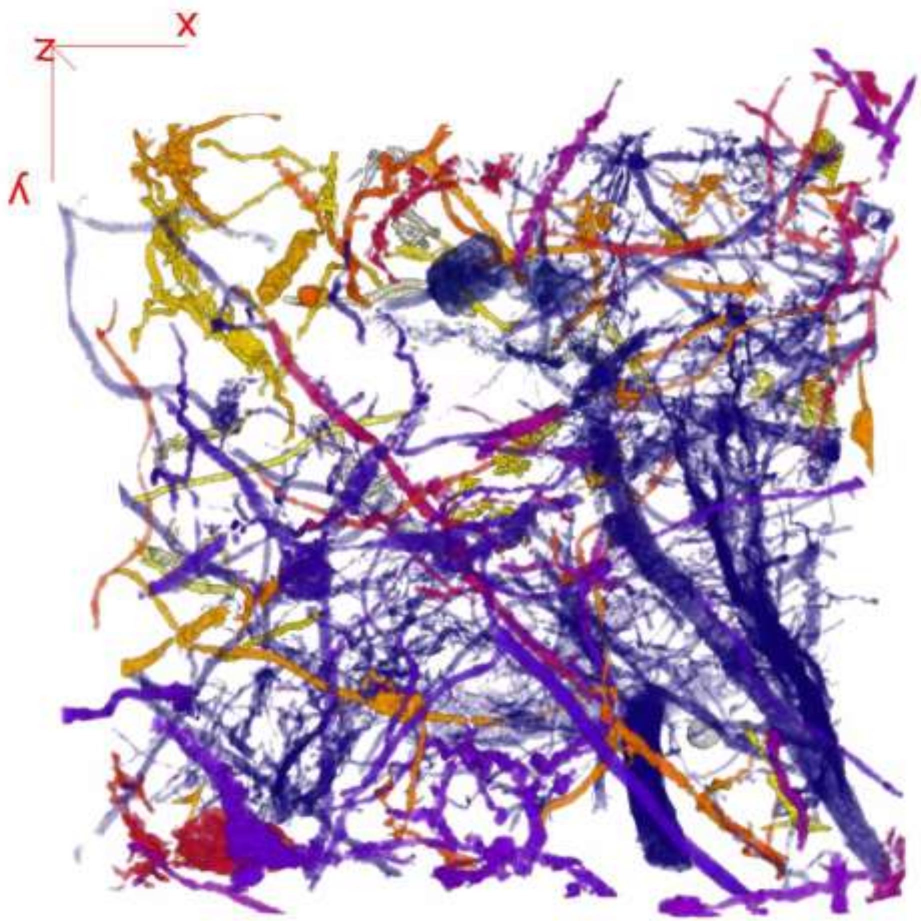
Future Works





Future Works





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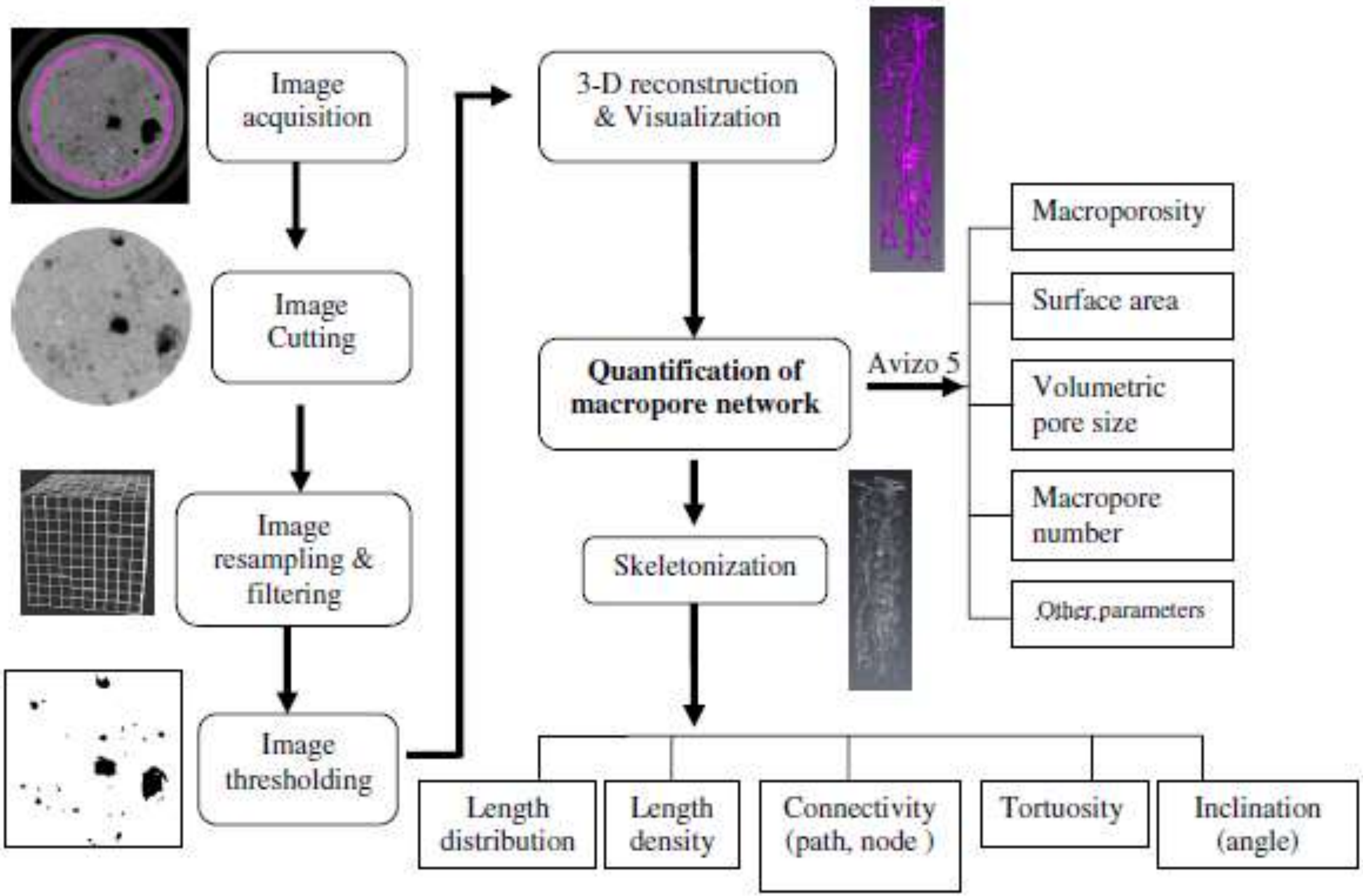

Concluding Remarks

- From 1985 to 2015 around 83 papers, thesis and dissertations were produced by Brazilian soil scientists in the CT field;
- Most part of the papers deals with analyses of soil bulk density and soil water content distribution in a non-invasive way;
- Changes in soil structure due to management systems, agricultural traffic, fertilizer and gypsum application have been studied;
- Nowadays, the Brazilian soil scientists are starting to use X-ray CT scanners of second and third generations for the study of soil microstructure in 3 dimension (3D);
- The high cost of these CT scanners still is a problem for the Brazilian scientists.

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