CIGR Section V International Symposium
CIGR Sección V Simposio Internacional

1 to 4 September 2009, Rosario, Argentina

Technology and Management to Increase the Efficiency in Sustainable Agricultural Systems

Tecnologías y Prácticas de Manejo para Incrementar la Eficiencia de Sistemas Agrícolas Sustentables

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The 10th Argentine Congress of Rural Engineering (CADIR) and 2nd of the Mercosur is taking place in the City of Rosario, Argentina, during the 1 to 4 of September of 2009. This is one of the most important and traditional Symposiums about agricultural and biological engineering in South America. The CIGR Section V has the pleasure to joint efforts with the organizing Committee of the CADIR Symposium to organize a broader and more interdisciplinary Symposium.

The title of the CIGR Symposium is "Technology and management to increase the efficiency in sustainable agricultural system", while the title of the CADIR Symposium is "The commitment of the Agricultural Engineering with the Regional Development".
The organizing committees of both Symposiums have the strong believe that this event will be of great benefit for scientist, scholars, professionals, students and companies of agricultural and biological engineering areas not only from Argentina and South America, but also for the entire world.
The CIGR Section V—"Management, ergonomics and systems engineering" Symposium is organized by the National Institute of Agricultural Technologies (INTA) and the University of Rosario, while the CADIR Symposium is organized by the University of Rosario, both institutions from Argentina.

Both Symposiums will present a joint technical program. People registered in the CIGR Symposium will publish their

El X Simposio Argentino de Ingeniería Rural y II del Mercosur (CADIR) se llevará a cabo en la ciudad de Rosario, Argentina, durante los días 1 a 4 de Septiembre de 2009. Este es uno de los Simposios más importantes y tradicionales sobre ingeniería agrícola y biológica de Sudamerica.
La Sección V de la CIGR tiene el placer de unir esfuerzos con el comité organizador del CADIR para organizar un Simposio más amplio e interdisciplinario.

El lema del Simposio de la CIGR es "Tecnologías y prácticas de manejo para incrementar la eficiencia de sistemas agrícolas sustentables", mientras que el lema del Simposio del CADIR es "El compromiso de la ingeniería rural con el desarrollo territorial".
Los comités organizadores de ambos Simposios están convencidos que será de gran beneficio para científicos, académicos, profesionales, estudiantes y empresas del área de la ingeniería agrícola y biológica no solo de Argentina y Sudamérica, sino que también del mundo entero.
El Simposio de la Sección V de la CIGR—"Ingeniería de manejo, ergonomía y sistemas agrícolas" es organizado por el Instituto Nacional de Tecnologías Agropecuarias (INTA) y la Universidad de Rosario, mientras que el Simposio del CADIR es organizado por la Universidad de Rosario, ambas instituciones de la República Argentina.

Ambos Simposios presentarán un

papers in the CIGR Symposium proceedings under the CIGR normative, while people registered in the CADIR Symposium will publish their papers in the CADIR proceedings under the CADIR normative. All the participants of both Symposiums will be able to assist to all technical sessions, since simultaneous translation English/Spanish and vice versa will be available. To learn more about the CIGR Symposium continue browsing this web page. To learn more about the CADIR Symposium follow the link (CADIR web).

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programa conjunto. Los inscriptos en el Simposio de la CIGR publicarán sus trabajos en los anales del Simposio de la CIGR bajo las normas de la CIGR, mientras que los inscriptos en el CADIR publicarán sus trabajos en los anales del CADIR bajo las normas del CADIR . Los participantes de ambos Simposios podrán asistir a todas las secciones técnicas, ya que se ofrecerá traducción simultanea Ingles/Español y viceversa. Para obtener más información sobre el Simposio de la CIGR siga navegando en este sitio web. Para obtener más información sobre el Simposio del CADIR siga el siguiente enlace (web CADIR).

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Instrumental Opportunities of X-ray Computed Tomography on Soil Compaction Characterization to Sustainability of Agricultural Production Systems

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ABSTRACT

The technologies of precision agriculture have allowed collecting information with better fidelity from soil physical properties. In this type of management, it takes into account the segmentation of a given agricultural area in a number of smaller cells and the use of inputs is performed with variable rates, leading to a lower impact on soil natural resources, mainly because only the needs locations are considered. This management technique leads to better sustainability in the use of agricultural soil. In this context of interest for precision farming, is found the use of X-ray computed tomography that has been useful, since the first work done in 1982. This paper discusses the various methods of X-ray tomography instruments and opportunities for the establishment of direct use in the field that allow the mapping of soil compaction, which has an impact on the movement of water and nutrients, and also on plants rooting.

Keywords: X-ray tomography, precision farming, sustainability, agricultural soil, compaction, Brasil

1. INTRODUCTION

The constant growth of world population is increasing demand for food and, consequently, for land to cultivate it. On the other hand, to increase the cultivation area it is necessary deforest native forests, which goes against the ecological concern. The intensified use of land, the environment degradation and the planet climate changes are requiring technologies that manage and sustain the use of soil and water resources. All these factors make the agriculture sustainability crucial to the balance between the pressures on these resources and the growing agricultural productivity.

The sustainability of agricultural systems will be built by combination of scientific knowledge about the physical and chemical properties of soil and water resources with a philosophical and cultural change in the use of these resources economically. To increase agricultural production, with technology and scientific support, the farmers must: (i) to intensify the use of good quality lands, (ii) to expand, to maintain, and to enhance production on lands previously viewed as "marginal", such as steep lands and semiarid tropics, and (iii) to restore degraded lands. The latter commonly has problems as soil compaction, loss of soil organic matter, reduced activity by soil organisms, nutrient deficiencies and imbalances and erosion (Committee on International Soil and Water Research and Development et al., 1991).

It is not a simple task to recover a degraded soil. The soil is a complex system and the main reasons for such complexity are its natural porous medium formed by the action of climate and microorganisms. As a result of those processes, soil is highly variable and heterogeneous and its contents are different minerals and organic materials in its composition. The soil porosity is responsible for transport processes and water storage, influencing this way the adsorption and reactions of solutes in soil solution (Crestana and Vaz, 1998). When the soil porous medium is compacted, it increases the resistance of roots growth, reduces the water infiltration into the soil, causing water and nutritional plants deficiency. Consequently the roots grow superficially and increase the risk of erosion (Gonçalves et al., 2006). It is crucial to know the soil compaction effects to improve soil management and, this way, increase the crop production.

The aim of this paper is to present some methods and instrumental opportunities of X-ray computed tomography on soil science and what sense they can help and improve the soil analysis research. Furthermore, it will present four trends of X-ray computed tomography to studies in soil science: (i) the determination of soil physical features and the study of volumetric water soil content, (ii) the quantification of soil structure by using different mathematical approaches, (iii) the growth quantification of plant roots and (iv) the analysis of earthworm burrow system for soil structure.

2. BASIC PRINCIPLES

The word tomography is composed by two Greek words: *tomo*, meaning slice or section and *graphy*, meaning to write or display. The tomography is a three-dimensional image of the internal structure of the sample under analyses. It is based on a large number of transmissions measurements of the attenuation of radiation beam.

There are four effects that occur between X-rays and the sample: Raleigh (coherent) scattering, photoelectric effect, Compton effect and pair generation (Duliu,1999). The attenuation of X-ray, due to passage through the sample, following the Beer's law:

$$I = I_0 \cdot e^{-\mu x} \tag{1}$$

where I_0 is the photons that reach the sample; I is the photons that crossed the sample; μ is the linear attenuation coefficient of sample; and x is the sample width. The linear coefficient μ depends of effective atomic number Z_{ef} and the density ρ of sample under analysis, as the semiempirical relation presents (Jacobs et al., 1995):

$$\mu = \rho\left(a + bZ^{3.8} / E^{3.2}\right) \tag{2}$$

where a represents the nearly energy-independent Klein-Nishina coefficient and b is a constant. The first term in equation 2 is related to Compton scattering and the second term is related to photoelectric absorption. The X-ray energy range between 30 and 200 keV, only coherent scattering, photoelectric and Compton effects occur. The pair production occurs at energies greater than 1.022 MeV. In the case of predominance of the Compton effect, the linear attenuation coefficient μ depends more of the density of the sample than its chemical composition. In contrast, the photoelectric effect depends more of the chemical composition of the sample (fig.1).

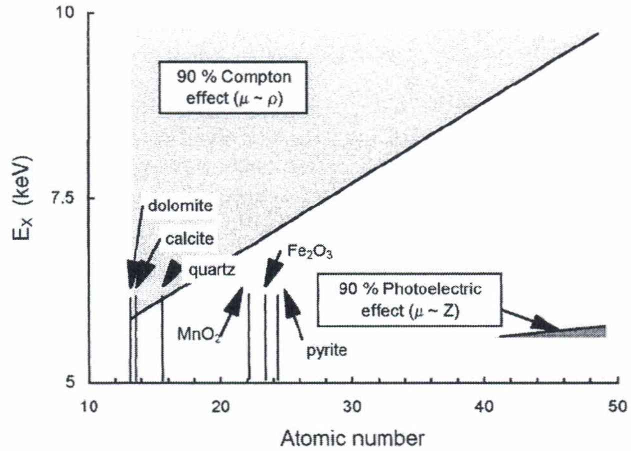

Figure 1. Graphical representation of the dependency of the ratio of Compton and photoelectric effects cross-section on the atomic numbers (Duliu, 1999).

The beam propagation leaves from source to detector and generate values which raise the projections. From a set of projections and with an appropriate algorithm for the reconstruction is possible to generate a physical information map of the sample under study, such as maps of linear attenuation coefficient, or other, the section under study. The acquisition of tomographic images, from a three-dimensional sample *f(x,y,z)*, occurs from the reconstruction of its projections. The coefficients map is represented by volume elements (voxels) and each voxel is characterized by an average value of the linear attenuation coefficient (fig. 2). Each value is given by a number called CT (Computerized Tomography) and is normalized according to the water attenuation coefficient (Cruvinel and Balogun, 2007).

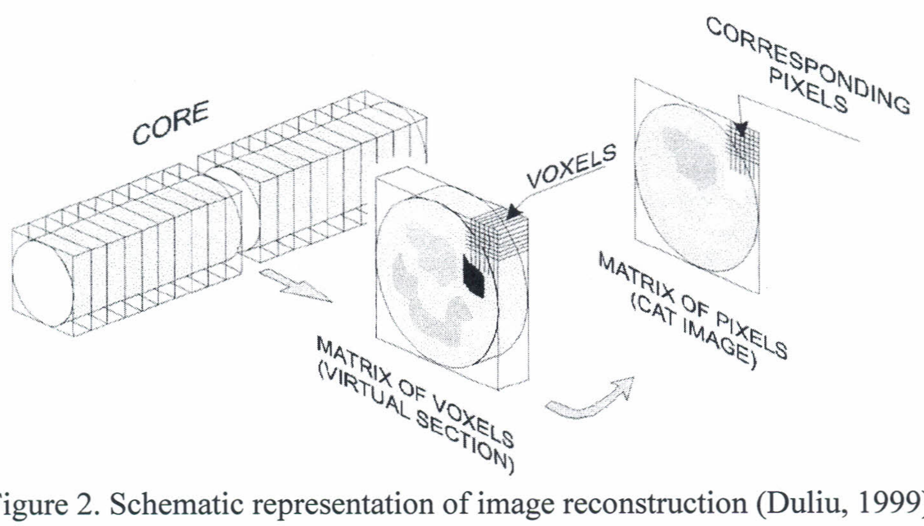

Figure 2. Schematic representation of image reconstruction (Duliu, 1999).

3. TRENDS OF X-RAY TOMOGRAPHY APPLIED TO SOIL SCIENCE

The X-rays have been a useful analysis tool since your first use: an examination of a fossil (Brühl, 1896). The major X-rays advantage is furnish quantitative as well as qualitative information about local density from samples in non-destrutive manner, i.e., the object maintain its structure or properties during the analysis.

The union of X-ray physics, detector technology and theory mathematical reconstruction allow the development of a pioneer technique called computer assisted tomography (CAT) and published by Godfrey N. Hounsfield (1972). The CAT allowed showing three-dimensional image of the internal structure of the object under examination, in a nondestructive manner, using measurements of the attenuation between the radiation and the material in which the object is composed. Initially, the CAT was applied to medical diagnostic, reducing the necessity of exploratory surgery. In the same year, Allan M. Cormack published a method of reconstruction of densities from their projections with applications radiological physics (1972) and in 1979 both Hounsfield and Cormack received the Medicine Nobel Prize.

In 1982, Petrovic et al. (1982) were pioneer in apply of CAT in soil science. Petrovic analyzed the CAT response near the upper limit of the measurement range where denser materials are located. They used soil and glass bead-air filled sphere as samples and the bulk density range obtained was from 0.14 to 1.64 $g.cm^{-3}$ with a good three-dimensional spatial resolution from 1.25 by 1.25 by 2 mm^3 to 6.4 mm in diameter by 2 mm. After these pioneer results, some trends were appearing with good results in soil science. Some examples are the study of volumetric water soil content and bulk density of soil columns, the quantification of soil structure by using different mathematical approaches, the growth quantification of plant roots and the analysis of earthworm burrow system for soil structure.

2.1 Volumetric water soil content and evaluation of soil structure

The study of soil compaction commonly uses values of dry bulk density and total porosity. These physical features of soil interferer directly water circulation around plant roots which consequently prejudice the plant nutrition. Hainsworth and Aylmore (1983) and Crestana et al. (1985) used an X-ray CAT scanner to measure soil water content and the motion of water in soil in three dimensions. It becomes possible studies of soil-plant water relations.

Measurements did with X-ray CAT were an expensive technique compared with other techniques existing at the time. Crestana et al. (1986) constructed a very inexpensive, homemade CAT miniscanner dedicated to soil science. The most advantage of this CAT was the possibility of varying the monoenergetic incident energy by varying the secondary target coupled to the X-ray tube. This feature became possible to select the optimal energy of the radiation to obtain the best analysis conditions.

The soil texture, which is defined by the size distribution of particles, and soil structure, defined by the combination of particles in aggregates, are the two most important soil physical properties. The assessment of the textural pores inside aggregates and macropores between the aggregates will define whether the soil matrix is structured or not. Phogat and Aylmore (1989) proved that the attenuation coefficient of soil and the macroporosity such as the total soil porosity had a strong linear correlation (r = 0.995). Cruvinel et al. (1990) constructed a new homemade X- and Gamma-rays computerized minitomograph scanner for assessment of volumetric water content θ with an accuracy of ± 3% and soil bulk density density ρ ± 2% (in grams/centimeters^3). This minitomograph obtained a very good linear relationship of 0.970 between the linear attenuation coefficient and the water content of soil, using images reconstructed by using the filtered back-propagation algorithm with a Ram-Lak filter.

The possibility to measure soil bulk density and water content, to obtain two- and three-dimensional images of soil samples, independent of geometry and shape, became the CATs very important to several problems diagnosis in soil science. Grose et al. (1996) used a CAT to assess the spatial examination of the response of soil water to environmental treatments of the soil-root system and the non-destructive observation of the effect of the spatial heterogeneity of volumetric water content upon fungal growth in the soil. Olsen and Børresen (1997), to reduce problems with soil erosion in Norwegian soils, used an X-ray CAT to analyze the effect of an increased number of macropores on solute infiltration between soil with conventional tillage practice and soil with reduced tillage. The results shown that the soil with reduced tillage (rotavating) the density is roughly uniform and in the underground the macroporosity was higher on rotavated than ploughed soil, i.e., the ploughing increases compaction compared to rotavation.

In 1998, Macedo et al. constructed a tomography with a methodology for soil non-invasive investigation in microscale and called X-ray microtomography (Macedo et al., 1998). This equipment work at a resolution of at least 100 μm and it was possible to observe a crack, inside one of the grains, of 110 μm wide per 460 μm and grains of densities up to 4.5 g/cm^3. The rainstorm changes the physical properties of soil surface causing sealing, variations in bulk density, surface roughness and others. Fohrer et al. (1999) analyzed the variation of bulk density within the first centimeter caused by single rainstorm and subsequent rainstorms. The results obtained by them for bulk densities were 1.35 – 1.48 g.cm^{-3} for uncrested and 1.74 – 1.88 g.cm^{-3} for crusted soil.

Cruvinel and Balogun (2000) published a new approach in tomographic instrumentation based on dual-energy Compton scattering. The results of this new tomography showed a linear relationship independent of soil aggregate sizes with regression coefficient better than 0.95 for bulk density and 0.70 for water content. The precision obtained for a minimum detectable density for 0.13 g/cm^3 and 0.10 g/cm^3 was 2% and 5% respectively. Macedo et al. (2000) used an X-ray microtomography to observe growth rings and radial variation of density. This variation showed a gradual increase in density from earlywood to latewood and a sharper decrease from latewood to earlywood. For Tsuga heterophylla sample, the global density obtained was 0.438 g/cm^3 and for Liquidanbar styraciflua was 0.603 g/cm^3.

The presence of grass in a watershed may reduce the water runoff and soil erosion because alters the soil macroposity partially. Rachman et al. (1995) used an X-ray tomography to characterize macroporosity of soil under perennial grass hedge system for 12 yr and to compare CT-macroporosity results

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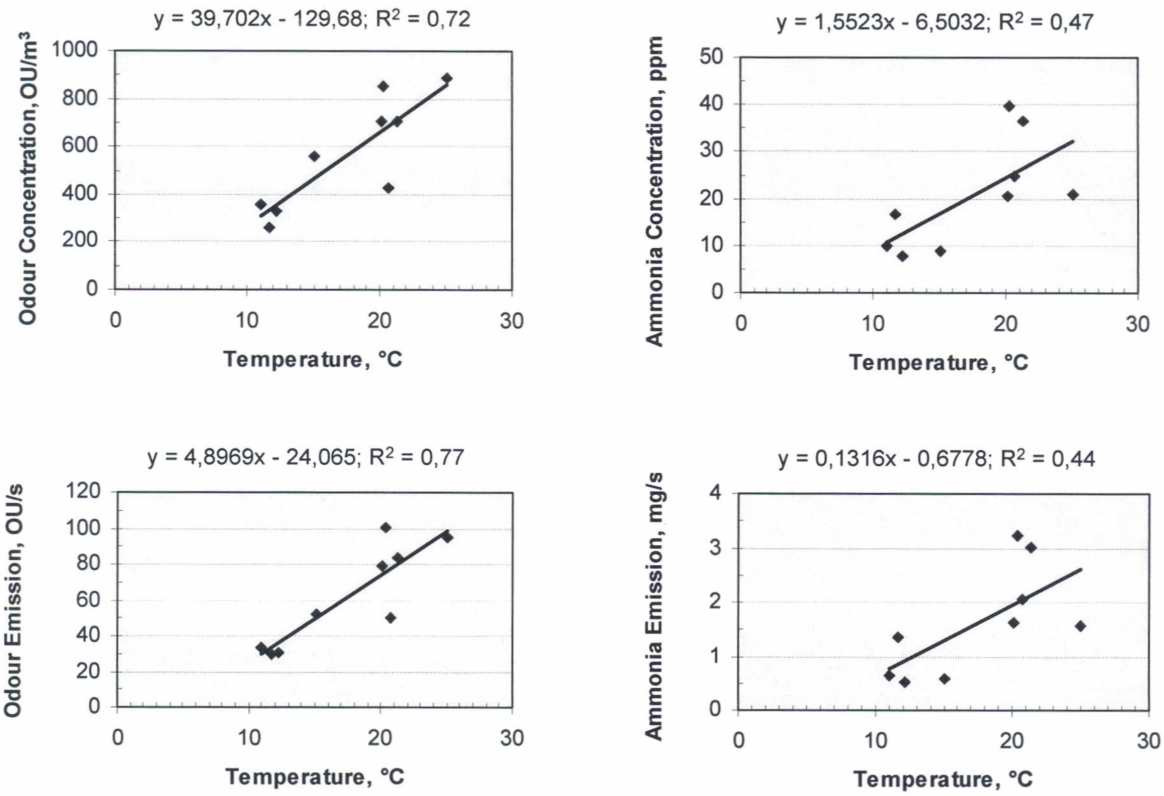

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Day	Air Flow Rate Chamber	Temperature in the Exhaust Air Mean	Minimum	Maximum	SD
No.	m^3/h	° C	° C	° C	
0	374	20.2	19.9	20.7	0.282
3	1909	20.4	19.6	21.4	0.622
4	1909	21.0	20.1	21.8	0.473
8	1020	18.4	17.4	19.3	0.601
11	727	19.7	18.9	20.2	0.434
15	334	15.6	14.1	16.9	0.960
18	338	12.6	11.1	14.0	0.964
22	338	11.0	9.6	12.0	0.761
25	422	11.8	10.5	12.9	0.765
29	422	20.2	19.3	21.0	0.568
31	427	21.1	20.3	21.9	0.505
35	427	20.8	19.8	21.6	0.625
37	402	20.3	19.2	21.2	0.747
45	383	25.0	24.2	25.7	0.538

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Unpublished Information

Unpublished references include personal communication, interviews, mimeographed reports, theses or dissertations. Identify these as well as unpublished results and other source material in the text within parentheses; include the source, the year (if available), title, location, or other information needed to establish the authenticity of the reference.

For example, (Alan Smith, personal communication with author, Gainesville, Fla., 21 June 1987)

or (William Chancellor, interview by author, Davis, Calif., 1 August 1995).

If the information is included in the reference section, use the form (Smith, 1987) in the text and the following format as with other references:

Smith, A. 1987. Personal communication with author. Gainesville, Fla., 21 June.