SEMINAR REPORT

SYNCHROTRON BASED TECHNIQUES IN SOIL SCIENCE

By

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Department of Soil Science and Agricultural Chemistry

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DECLARATION

I, Gadha V. P. (2018-11-107) declare that the seminar entitled **“**synchrotron based techniques in soil science**”** has been prepared by me, after going through various references cited at the end and has not been copied from any of my fellow students.

Vellanikkara
06-12-2019

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2018-11-107

CERTIFICATE

This is to Certify that the seminar report entitled **“**synchrotron based techniques in soil science**”** is a record of seminar presented by Gadha V.P.(2018-11-107) on 6th December, 2019 and is submitted for the partial requirement of the course SOILS 591.

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1. Introduction

Synchrotron radiations are emerging as a real-time probing tool for the wide range of applied sciences. Synchrotron radiations have unique properties because of their high brilliance, collimations, broad energy spectrum, and coherence power that break the limits to characterize the material properties than previous laboratory-based tabletop sources. The third-generation synchrotron light sources are capable of producing 1012 times higher brilliance than laboratory-based sources using insertion devices.

Spectroscopic approaches to plant and soil sciences have provided important information for several decades. However, many of these approaches suffered from a number of limitations and drawbacks especially in terms of spatial resolution and requirements for sample preparation. The advent of dedicated synchrotron facilities, that allow the exploitation of the particular qualities of synchrotron radiation as a research tool, has revolutionized the way we approach the investigation of nutrients and contaminants in environmental samples. Various synchrotron-based techniques are currently available that permit such investigations in situ and at the molecular level. The continuous development of these techniques is delivering substantial gains in terms of sensitivity and spatial resolution which allows analyses of diluted samples at the sub-micron scale

2. Synchrotron

Synchrotron is basically a cyclic particle accelerator in which charged particles are forced to follow curved trajectories under applied magnetic fields and due to such motion, they emit electromagnetic radiations (infrared to hard X-rays) known as synchrotron radiations (Balerna and Mobilio, 2015). Synchrotron radiations (SR) have unique properties because of their high brilliance, high polarisation, broad energy spectrum, and time structured emission that breaks the limits to characterize the material properties than previous laboratory-based tabletop sources. So these radiations are emerging as a real-time probing tool for the wide range of applied sciences.

2.1 Definition

A particular type of cyclic particle accelerator that produces synchrotron radiation (SR).Synchrotron light generally designates the electromagnetic radiation emitted when electrons, moving at velocities close to the speed of light, are forced to change direction under the action of a magnetic field.

2.2 Particle accelerators

Particle accelerators are specially designed machines that are used to accelerate the elementary particles to desired energy range. The accelerated particles may be Protons, neutrons, deuterons, electrons, etc they should be introduced to the accelerator using proper accelerating voltage. Once the particle enters the accelerator, then it is under electric/magnetic field and accelerated up to the desired energy, then the particles are extracted out of the accelerator. Divided into two ie, acceleration by time varying field and acceleration by constant field. In case of constant field- the particles are accelerated using constant potential difference (electrostatic accelerators). Accelerators with Acceleration by time varying field again divided into two- linear accelerators and cyclic accelerators**.**

Cyclic Accelerators- When particles form closed-path again and again, then they get accelerated. The accelerators that work on closed-path orbits and yield high energy particles are known as cyclic accelerators. eg. cyclotron, synchrotron. etc. in the cyclotron, accelerating charged particles to very high energies involves the repeated application of an oscillating electric field. If a very large number of individual accelerations is required, there may be difficulty in keeping the particles in step with the electric field. In order to accelerate the particles it is now necessary to change value of the either the magnetic field or the frequency.

3. Components of Synchrotron

A synchrotron is composed of six main components

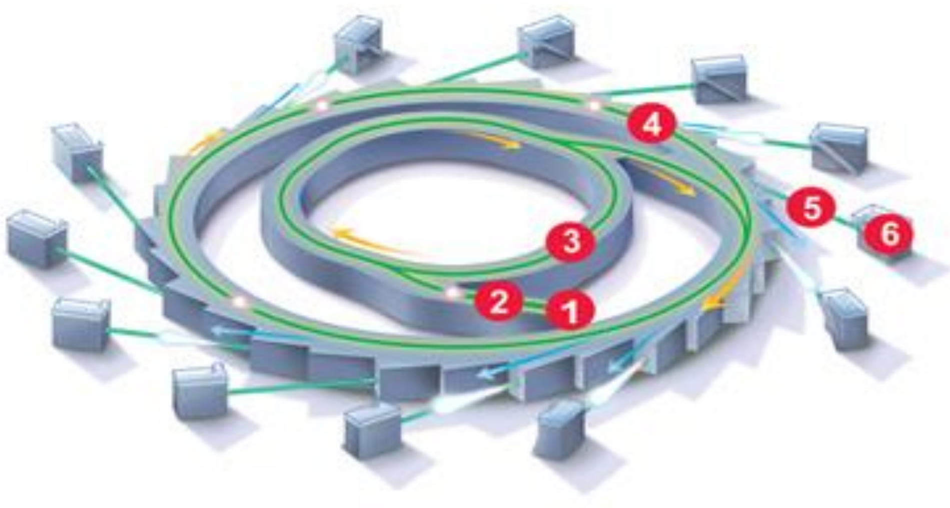

Plate 1 - diagrammatic view of synchrotron

1. Electron source
2. Linear accelerator
3. Booster ring
4. Storage ring
5. Beam lines
6. End station

3.1 working principle

In general, electrons are generated by the thermionic emission from a hot filament (electron gun) which serves as a source. The electrons are then accelerated by either microtron or linear accelerator (LINAC) to several hundred MeV of energy. The electrons are then injected to a circular accelerator to boost its energy to approach main storage ring electron energy, called booster ring. Electrons are periodically transferred to storage rings from booster when storage ring current falls to 1–1/e _ 70% to maintain beam current. The storage ring is the main component of a synchrotron, in which electrons travel in a closed path under the effect of magnetic field. The main magnetic components are a set of magnets: bending (dipole), quadruple and sextuple magnets, so-called magnet lattice. Bending magnets force the electrons to follow the closed path, and the beam is focused by quadruple magnets via compensating electronic coulomb repulsion. Sextuple magnets serve as a corrector for chromatic aberration governed from quadruple focusing. The modern ring structure consists of a periodic arched section having bending magnets and straight sections composed of insertion devices that are used to produce intense synchrotron radiations, which are named as the “third-generation storage ring”. The beamlines are working along the axes of insertion devised and tangential to bending magnet and the storage ring. The beamlines are designed for specific dedicated applications, i.e., X-ray imaging (tomography), X-ray absorption spectroscopy (X-ray absorption fine structure (XAFS), near-edge and extended-edge spectroscopy (XANES, EXAFS)), X-ray scattering (small- and wide-angle X-ray scattering) and X-ray fluorescence/emission spectroscopy (XRF) etc. These beam lines will enter into the end station where further analysis takes place.

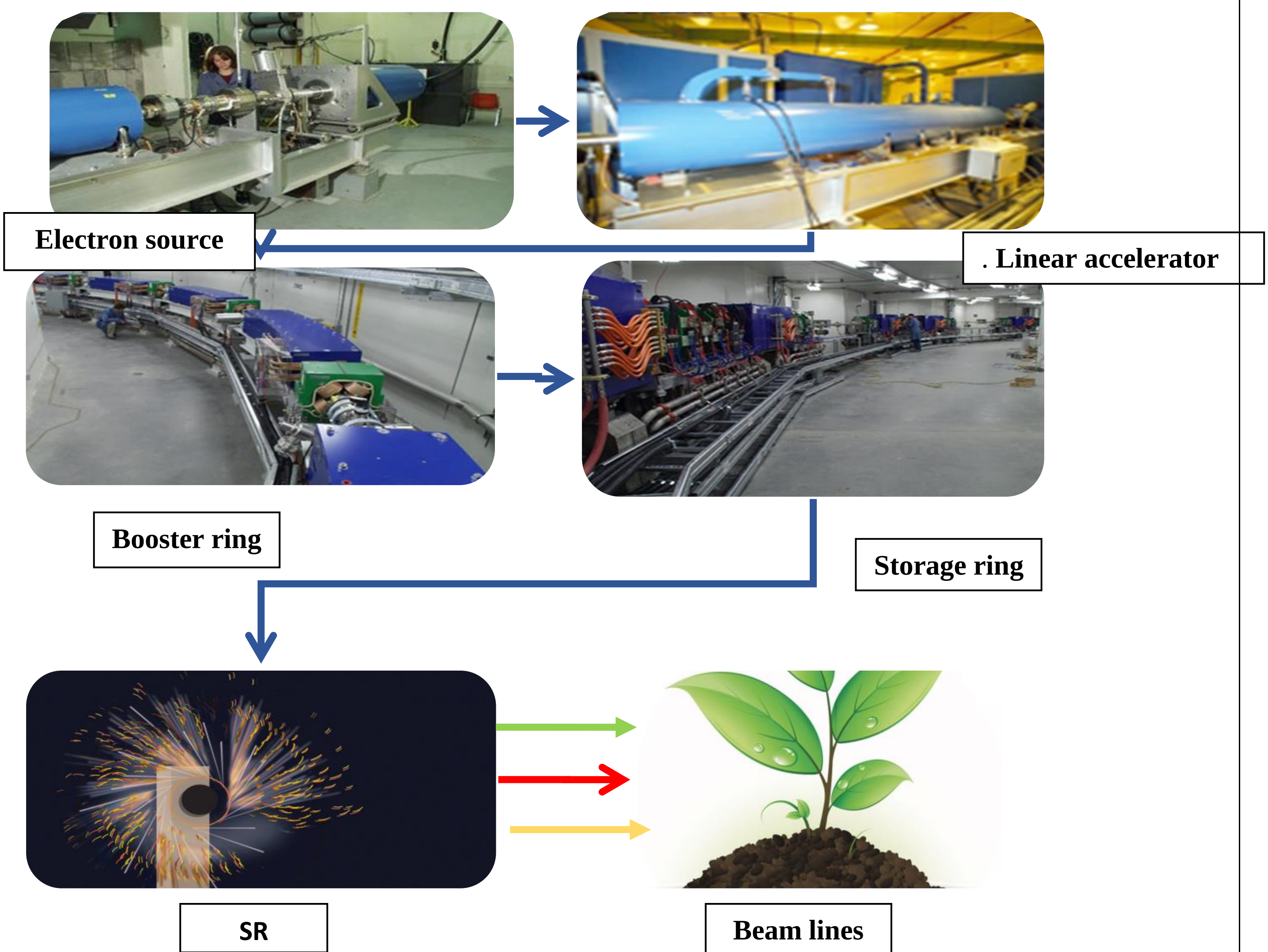

Plate 2- flow chart showing working of synchrotron

4. synchrotron radiation (SR)

EMR emitted by charged particles moving at higher velocities in curved trajectories under applied magnetic fields with wavelengths ranging from Infrared to hard X-rays.

4.1 Unique properties of SR

- High brightness: synchrotron light is hundreds of thousands of times more intense than that from conventional X-ray tubes and is naturally highly collimated.
- Wide energy spectrum: synchrotron light is emitted with energies ranging from infrared light to hard X-rays. Furthermore the emitted light is tunable.
- Highly polarised: the synchrotron emits highly polarised radiation, which can be linear, circular or elliptical.
- Time-structured emission: nano-second long light pulses enable time-resolved studies.

4.2 Advantages over normal rays

- Sensitivity due to the high flux availability
- Weak scattering and High collimation
- Wide selection of wavelength and Possibility of beam tunability
- High stability
- High penetration capacity

5. History and Development of synchrotron

- 1944- Vladimir Veksler Principle of synchrotron

- 1945 Edwin McMillan First electron synchrotron
- 1952 Marc Oliphant First proton synchrotron
- 1958 Courant and Snyder AG (Alternative-Gradient) principle

Brilliance/brightness of the emitted radiation beam has been enhanced over the years as the technology evolves. The synchrotron sources enhanced the brilliance of radiations 20 times than that of X-ray tubes/ laboratory-based sources. Due to such a high brilliance, synchrotron radiations are able to explore the deep-inside of materials properties and of utmost interest of scientific research community. In third-generation synchrotron source, both ofthese quantities can be tuned according to the experimental requirements. Insertion devices have been installed in the storage ring to enhance the flux and brilliance of photon beam.

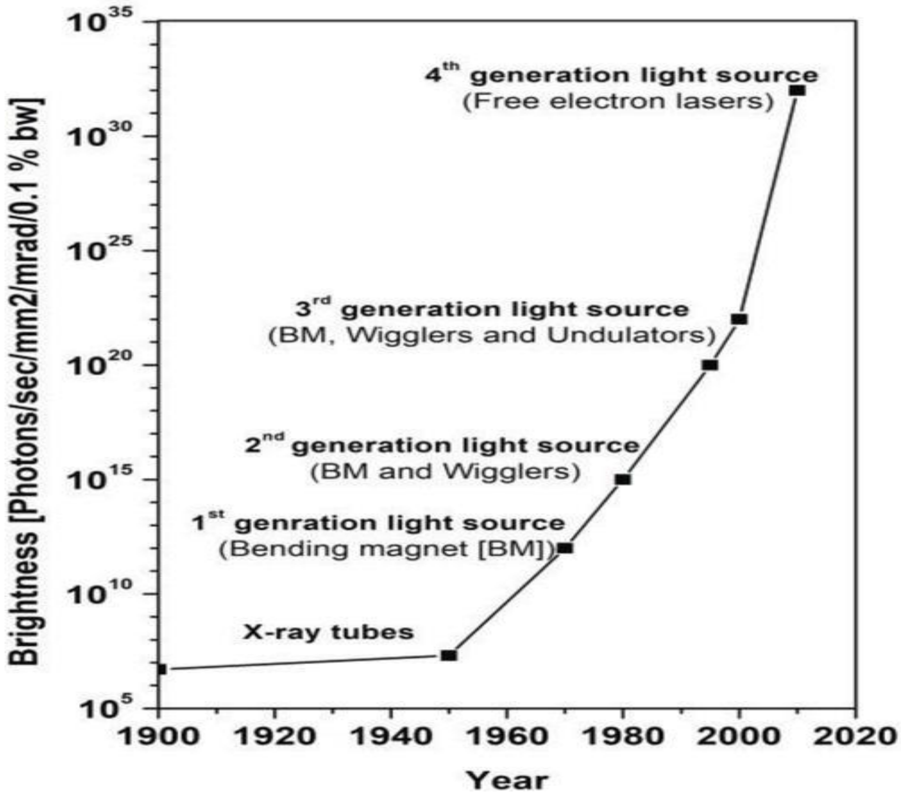

Fig 1- Brightness enhancement graph

Early construction of high-energy particle accelerators started essentially after World War II and enabled first generation machines. They were built in order to understand the fundamental laws of matter and particle interactions.

• Second generation: dedicated light source facility with multiple user programs

• Third generation sources started operation in the early 1990s: high brightness, optimized accelerator performance

• Fourth generation machines: diffraction-limited X-ray beams

Facility	Country	Energy [GeV]	Current [mA]	Periphery [m]	Emittance [nm-mrad]	Brilliance [ph/s/ $mrad^2/mm^2$/0.1%bw]
Spring8	Japan	8.00	100	1436.00	2.80	2.0×10^{21}
APS	USA	7.00	100	1104.00	3.00	8.0×10^{19}
PF-AR	Japan	6.50	60	377.00	294.00	4.0×10^{13}
ESRF	France	6.00	200	844.00	3.80	8.0×10^{20}
PETRA-III	Germany	6.00	100	2304.00	1.00	2.0×10^{21}
CHESSS	USA	5.29	200	768.43	101.70	10^{15}
SSRF	China	3.50	300	432.00	3.90	10^{20}
Candle	Armenia	3.00	350	216.00	0.08	1.7×10^{13}
AS	Australia	3.00	200	216.00	7.00	4.6×10^{18}
Diamond	England	3.00	300	562.00	2.70	3.0×10^{20}
SLAC	USA	3.00	500	234.00	0.01	2.0×10^{13}
PAL	South Korea	3.00	400	281.82	5.80	2.0×10^{11}
ALBA	Spain	3.00	100	268.80	4.58	4.0×10^{12}
NSRRC	Taiwan	3.00	500	518.40	1.60	10^{16}
NSLS-II	USA	3.00	500	792.00	0.60	3.0×10^{21}

CLS	Canada	2.90	250	171.00	18.10	1.5×10^{11}
SOLEIL	France	2.75	500	354.00	3.70	10^{20}
ANKA	Germany	2.50	200	110.00	50.00	10^{18}
INDUS-II	India	2.50	200	110.00	50.00	10^{13}
PF	Japan	2.50	450	187.00	36.00	3.0×10^{14}
Elletra	Italy	2.40	320	260.00	7.00	10^{19}
SLS	Switzerland	2.40	400	288.00	5.50	5.0×10^{15}
BSRF	China	2.20	100	240.40	7.60	7.0×10^{12}
MAX-IV	Sweden	2.00	500	528.00	0.17	2.2×10^{21}
ALS	USA	1.90	100	240.00	6.80	3.0×10^{18}
BESSY-II	Germany	1.70	100	240.00	6.00	5.0×10^{18}
SAGA	Japan	1.40	300	75.60	25.00	10^{13}

Table 1.Important parameters of the world's top third-generation synchrotron light sources, tabular in order to decrease storage ring energy.

6. Indian synchrotrons

RRCAT (Raja Ramanna Centre for Advanced Technology) has developed two synchrotron radiation sources called "Indus": Indus-1 is a 450 MeV electron storage ring, whereas Indus-2 is a booster cum storage ring that can accelerate electrons from an injection energy of 550 MeV to 2.5 GeV.

Indus-1

The first Indian synchrotron source Indus-1, a 450 MeV electron storage ring, was commissioned in early 1999. It provides a broad electromagnetic spectrum extending from far infrared to soft x-ray region. It has opened up a possibility to carry out research activity using the soft x-ray/ vacuum ultraviolet radiation (10Å < λ < 1000Å) in India. This wavelength band covers many absorption thresholds of various elements. In addition, due to its shorter wavelength it posseses great capability to explore physical structure with much better resolution than that offered by the visible light.

Different beamlines have been planned and installed for carrying out different kinds of experiment on Indus-1. Among those, the CAT reflectometry and AIPES (angle integrated PES) beamlines were commissioned in Nov 2000. Later three more beamlines including ARPES (angle resolved PES), photo physics, and high resolution VUV beamlines were also commissioned.

Indus-2

Indus-2 is a synchrotron radiation source with a nominal electron energy of 2.5 GeV and a critical wavelength of about 1.98 angstroms. It is one of the most important projects in progress at RRCAT. It is designed to cater to the needs of X-ray users, material scientists and researchers. Indus-1 has the distinction of being the first synchrotron generator of India with a 450 Mev storage ring. Indus-2 is an improvement over Indus-1. Indus-2 lattice has been designed in such a way as to give low beam emittance and high brightness. The lattice is a Double Bend Acromat with zero dispersion function along the long straight section. It has eight super periods each having two dipole bending magnets, four focusing and five defocusing quadrupoles and six sextupoles. Of the eight long straight section, three will be used for injection and RF cavities respectively. The remaining five will be used for insertion devices.The radiation source Indus-2 is in an advanced stage of construction near Indore, Madhya Pradesh.

7. Basic synchrotron techniques used in soil

Main synchrotron techniques used in soil are-

- x ray absorption spectroscopy (XAS)
- x ray fluorescence (XRF) techniques
- x-ray computed μ-tomography (SR-μCT).

7.1 X-ray absorption spectroscopy (XAS)

The absorption of X-ray photons by matter is controlled by the photo-electric effect which is exploited by experimentalists to obtain information in relation to one or more elements of interests. It is important to keep in mind here that one of the key characteristics of synchrotrons is the capacity to provide an energy-tunable source of X-rays. This is essential in X-ray absorption spectroscopy since the techniques based on this principle. When the energy of an X-ray that reaches a sample is lower than the binding energy of the core electrons of the element of interest, the atoms of this element do not participate to the absorption process. With increasing energy of the incident X-ray photons a point is reached where their energy is approximately equal to the binding energy of the core level electrons for the element of interest. At this point a sharp increase in absorption of the X-ray photons occurs. This is accompanied by the production of photoelectrons due to the excitation of core electrons by the incident X-rays and ejection of the photoelectrons from the atoms into the continuum (Hesterberg *et al*., 2014).

XAS is a powerful technique that provides detailed information regarding the chemistry of an element in basically any matrix ranging from minerals, to biological specimens and solutions. This technique is generally available only at synchrotrons since it requires both high X-ray fluxes and tenability. The XAS spectrum is conventionally divided in two energy regions which also give name to the two main XAS techniques: X-ray absorption near edge spectroscopy or near edge X-ray absorption fine structure (XANES or NEXAFS) and extended X-ray absorption fine structure (EXAFS). The part of the spectra covered by XANES extends from the pre-edge region to approximately 50 eV above the absorption edge.

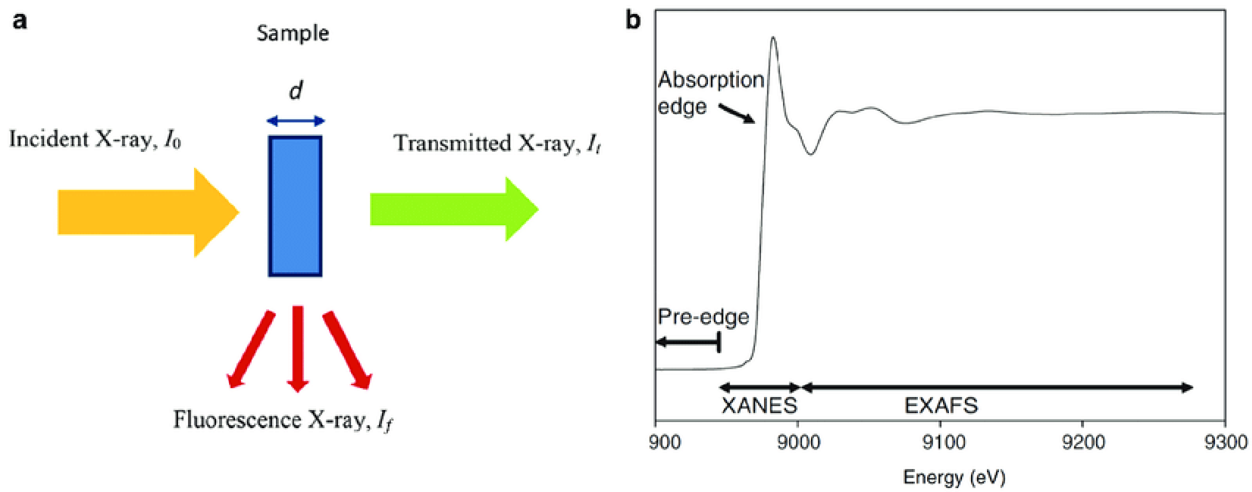

Fig. 2 XAS spectrum of malachite [$CuCO_3.Cu(OH)_2$] showing the region of the spectrum pertinent to XANES and EXAFS

7.2 X-ray fluorescence (XRF)

After the ejection of photo electron in order for the atom to return to the ground state, an electron from a higher energy level fills the vacancy left by the expulsion of the photoelectron. The difference in energy between the two electron levels is emitted in the form of fluorescence. XRF techniques are based on the principle discussed above and permit mapping, and often quantification, of the elements present in a sample in a similar way as it is possible with non-synchrotron techniques such as SEM-EDXA and PIXE. The advantage of SR-XRF lies in its sensitivity, due to the high photon flux available, the possibility of beam tunability and weak scattering. Quantification is comparatively straightforward because the physics of photons interaction with matter is simpler and well understood (Lombi and Susini, 2009).

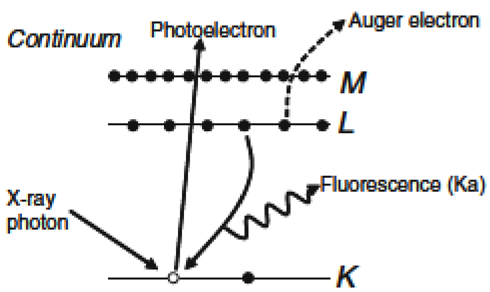

Plate 3- Depiction of the excitation of an atom by an X-ray photon and decay of the excited state by either X-ray fluorescence or by the Auger effect. K, L and M are the core electron levels.

7.3 X-ray computed μ-tomography (SR-μCT)

The knowledge of the elemental variation along three dimensions intrinsically improves the data quality and therefore its interpretation. SR-μCT allows the observation of the internal structure or composition of a specimen without the need of physically sectioning it.

8. Synchrotron applications in soil science

8.1 Soil physical properties

- Soil water and air
- Pore size and distribution
- Cracks and crevices
- Soil aggregates
- Soil clays

Case study- Tillage system and cover crop effects on soil quality: II. Pore characteristics (Abdollahi *et al.*, 2014)

This study examined the effect of management practices on soil pore characteristics of a sandy loam soil in a long-term field trial. The tillage treatments (main plots) included direct drilling (D), harrowing to a depth of 8 to 10 cm (H), and moldboard plowing (MP). The cover crop treatments were subplot with cover crop (+CC) and without cover crop (−CC). results show that the cover crop created continuous macropores and in this way improved the conditions for water and gas transport and root growth. The cover crop thus alleviated the effect of tillage pan compaction in all tillage treatments

8.2 Soil chemical properties

- Nutrient assessment in soil
- Fate, availability and efficiency of different fertilizers in soil
- Investigation of redox-sensitive processes etc.

Case study- Performance of secondary P-fertilizers in pot experiments analyzed by phosphorus x-ray absorption near-edge structure (XANES) spectroscopy (Vogel *et al*., 2017).

A pot experiment was carried out with maize to determine the phosphorus (P) plant-availability of different secondary P-fertilizers derived from wastewater. Macro and micro XANES spectroscopy were used to determine the chemical state of the overall soil P and identify P compounds in P-rich spots. The observed reactions between phosphate from secondary P-fertilizers and co fertilized nitrogen compounds should be further investigated. Formation of highly plant-available compounds such as ammonium phosphates could make secondary P-fertilizers more competitive to commercial phosphate rock-based fertilizers with positive effects on resources conservation.

8.3 Soil biological properties

- Characterization of soil organic matter
- Study chemistry of microbial activity etc.

Case study- Three-dimensional soil organic matter distribution, accessibility and microbial respiration in macro aggregates using osmium staining (OsO_4) and synchrotron X-ray computed tomography (Rawlins *et al.*, 2013).

The spatial distribution and accessibility of organic matter (OM) to soil microbes in aggregates – determined by the fine-scale, 3-D distribution of OM, pores and mineral phases – may be an important control on the magnitude of soil heterotrophic respiration (SHR)

8.4 Soil-plant interactions

- Soil phytoremediation

- Absorption studies

Case study- SR induced micro-XRF for studying the spatial distribution of Pb in plants used for soil phytoremediation (Mera *et al.,* 2019).

The aim of this work was to perform a study by SR micro X-ray fluorescence technique of the spatial distribution of Pb in roots and leaves of two different species of plants potentially useful for soil phytoremediation. The experiments were conducted in *Brassica napus* and *Festuca arundinacea.* The plants were grown in Pb soil contaminated, in controlled environment, cultivated in greenhouses at CEPROCOR. The measurements were carried on at the D09B XRF Fluorescence beamline of the Brazilian Synchrotron Light Laboratory (LNLS), on different parts of the living plant. SR induced micro-XRF results showed that *Brassica napus* extracted Pb from the ground and translocated it to the leaves more effectively than *Festuca arundinacea*, grown in contaminated soil, where lead remained at the root. Furthermore, a co-distribution was observed between Pb and Zn, P, S and Fe. This suggest that *Brassica napus* is a potential plant to be used for phytoextraction of Pb from soil. The use of SR micro-XRF to map the distribution of metals in plant tissue allows significant advances in phytoremediation studies as well as in other topics of environmental sciences.

8.5 Soil pollution studies

- Speciation of soil contaminants
- Assessment of in-situ techniques for the remediation of contaminated soils
- Transport of contaminants

Case study- Speciation and distribution of copper in a mining soil using multiple synchrotron-based bulk and microscopic techniques (Yang *et al*., 2014).

Molecular-level understanding of soil Cu speciation and distribution assists in management of Cu contamination in mining sites. In this study, one soil sample, collected from a mining site contaminated since 1950s, was characterized complementarily by multiple synchrotron-based bulk and spatially resolved techniques for the speciation and distribution of

Cu as well as other related elements (Fe, Ca, Mn, K, Al, and Si). Bulk X-ray absorption near-edge structure (XANES) and extended X-ray absorption fine structure (EXAFS) spectroscopy revealed that soil Cu was predominantly associated with Fe oxides instead of soil organic matter

8.6 Rhizosphere science

- Rhizosphere structure of all plants (including aquatics)
- Distribution of heavy metals in the rhizosphere of contaminated soils
- Investigate the microbial micro-habitat structure
- Visualize the rhizosphere chemistry of plants

Case study- High-resolution synchrotron imaging to study the effect of root hairs on soil structure (Koebernick et al., 2017).

This paper provides direct evidence of the importance of root hairs on pore structure development at the root–soil interface during the early stage of crop establishment. This was achieved by use of high-resolution (c. 5lm) synchrotron radiation computed tomography (SRCT) to visualise both the structure of root hairs and the soil pore structure in plant–soil microcosms. Two contrasting genotypes of barley (*Hordeum vulgare*), with and without root hairs, were grown for 8 d in microcosms packed with sandy loam soil at 1.2 g cm^3 dry bulk density. Root hairs were visualised within air-filled pore spaces, but not in the fine-textured soil regions. found that the genotype with root hairs significantly altered the porosity and connectivity of the detectable pore space (> 5 lm) in the rhizosphere, as compared with the no-hair mutants. Both genotypes showed decreasing pore space between 0.8 and 0.1mm from the root surface. Interestingly the root-hair-bearing genotype had a significantly greater soil pore volume-fraction at the root–soil interface. Effects of pore structure on diffusion and permeability were estimated to be functionally insignificant under saturated conditions when simulated using image-based modelling.

CONCLUSION

Information at the molecular level is becoming increasingly important for a better understanding of the chemical and biological processes affecting the speciation, properties, and behavior of contaminants, pollutants, and nutrients in the ecosphere (Doe, 2003). In this context, a growing need for micro-spectroscopy and imaging facilities at SR sources can be envisioned. Future thrust lies in integrating SR techniques with molecular biology and plant physiology which would open up wider understanding of soil properties in relation to plant and environment.

The use of Synchrotron radiations with advanced spectrochemical multidimensional methods can provide the opportunity for a radical shift from entity driven research to process driven research thus resulting in holistic understanding of environmental processes.

Discussion:

1. What is the difference between synchrotron and cyclotron?

   In cyclotron, accelerating charged particles to very high energies involves the repeated application of an oscillating electric field. If a very large number of individual accelerations is required, there may be difficulty in keeping the particles in step with the electric field. In order to accelerate the particles it is now necessary to change value of the either the magnetic field or the frequency that is done in synchrotron.

2. What you mean by high collimation?

   High collimation means small angular divergence of beam *i.e.* less scattering.

3. Which are the other disciplines where synchrotron is used?

   It is applied in many disciplines like Material engineering, Medical imaging and therapy, Environment pollution, Forensics and Industrial applications.

4. What are the applications in medical field?

   In medical field it is used to identify kidney stones, angiography, mammography *etc.*

5. What is the advantage of synchrotron based X-ray micro-CT scan over normal CT scan?

   synchrotron based X-ray micro-CT (SR-μCT) has higher resolution, stronger contrast, and faster scanning speed, and is therefore an excellent tool for studying microstructure of soil aggregate

6. Even though it has a lot of applications, it exists very few in number throughout the world. Why?

The reason is its high cost of construction. Hundreds of billions of dollars required only for construction and still more is required for its maintenance.

References

Abdollahi, L. and Munkholm, L. J. 2014. Tillage system and cover crop effects on soil quality: pore characteristics. *Soil Sci. Soc. Am. J.* 78:218-226.

Balerna, A. and Mobilio, S. 2015. *Synchrotron Radiations: Basics, Methods and Applications.* Springer, Germany, pp. 3-27.

Doe, J. 2003. Molecular environmental science: an assessment of research accomplishments, available synchrotron radiation facilities, and needs, http://www.slac.stanford.edu/cgi-wrap/pubpage?SLAC-R-704 [30 Oct 2019].

Hesterberg, D., Duff, M. C., Dixon, J. B., Vepraskas, M. J. 2010. X-ray microspectroscopy and chemical reactions in soil microsites. *J. Environmental Quality* 40(3): 667-678

Koebernick, N., Daly, K. R., Keyes, S. D., George, T. S., Brown, L. K., Raffan, A., Cooper, L. J., Naveed, M., Bengough, A. G., Sinclair, I. and Hallett, P. D. 2017. High-resolution synchrotron imaging shows that root hairs influence rhizosphere soil structure formation. *New Phytologist* 216(1): 124-135.

Lombi, E. and Susini, J. 2009. Synchrotron-based techniques for plant and soil science: opportunities, challenges and future perspectives. *Plant Soil* 320:1-35.

Mera, M. F., Rubio, M., Perez, C. A., Cazon, S., Merlo, M. and Munoz, S. E. 2019. SR induced micro-XRF for studying the spatial distribution of Pb in plants used for soil phytoremediation. *Radiation Physics and Chemistry* 154:69-73.

Rawlins, B. G., Wragg, J., Reinhard, C., Atwood, R. C., Houston, A., Lark, R. M., and Rudolph, S. 2016. Three-dimensional soil organic matter distribution, accessibility and microbial respiration in macro aggregates using Osmium staining and synchrotron X-ray computed tomography. *Soil 2*(4), pp. 659-671.

Vogel, C., Rivard, C., Wilken, V., Muskolus, A. and Adam, C. Performance of secondary P-fertilizers in pot experiments analyzed by phosphorus X-ray absorption near-edge structure spectroscopy. *Ambio*. 47(1):62–72.

Yang, J., Liu, J., Dynes, J. J., Peak, D., Regier, T., Wang, J., Zhu, S., Shi, J., and John, S. T. 2014. Speciation and distribution of copper in a mining soil using multiple synchrotron-based bulk and microscopic techniques. *Environmental Science and Pollution Research*, 21(4): 2943-2954.

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SOILS 591: Masters Seminar

Name	: Gadha V.P.	Venue	: Seminar hall
Admission No.	: 2018-11-107	Date	: 06-12-2019
Major advisor	: Dr.Thulasi V.	Time	: 9.15 am

SYNCHROTRON BASED TECHNIQUES IN SOIL SCIENCE

Abstract

Synchrotron is basically a cyclic particle accelerator in which charged particles are forced to follow curved trajectories under applied magnetic fields and due to such motion, they emit electromagnetic radiations (infrared to hard X-rays) known as synchrotron radiations (Balerna and Mobilio, 2015). Synchrotron radiations (SR) have unique properties because of their high brilliance, high polarisation capacity, broad energy spectrum and time structured emission that break the limits to characterize the material properties than conventional laboratory-based tabletop sources. Hence these radiations are emerging as a real-time probing tool for wide range of applied sciences.

There are a number of synchrotrons in the world and many of these are fully or partially dedicated to the generation of synchrotron radiations for research. In India, RRCAT (Raja Ramanna Centre for Advanced Technology) has developed two synchrotron sources namely 'INDUS 1 & 2'. Many applications of synchrotron radiations are available in almost every field of science including physics, chemistry, biology, life sciences, geology, soil science and material science.

Main synchrotron techniques used in soil studies are X-ray absorption spectroscopy (XAS), X-ray fluorescence (XRF) techniques and synchrotron radiation computed μ-tomography (SR-μCT). X-ray absorption spectroscopy is a powerful technique that provides detailed information regarding the chemistry of an element. X-ray fluorescence techniques permit mapping and quantification of the elements present in a sample whereas SR-μCT allows the observation of the internal structure without physical sectioning of that object (Lombi and Susini, 2009).

The use of SR in soil science has increased dramatically in the last decade. SR techniques are used to assess soil physical, chemical and biological properties. SR techniques are also applicable in studies on plant-soil interactions, environmental pollution and rhizosphere science.

Recent, detailed and reliable speciation in soils for a large number of elements has been determined by combining sequential extraction with direct analytical methods exploiting high intensity synchrotron generated X-rays (Yang *et al*., 2014). Abdollahi *et al.* (2014) analyzed the pore structure and distribution in soil to understand the tillage system and cover crop effects on soil quality with SR-μCT.

Root hair interactions with soil structure can be investigated *in situ* with sufficient resolution due to recent advances in non-invasive synchrotron radiation computed tomography (SRCT) (Koebernick *et al*., 2017). The use of SR micro-XRF technique to map the distribution of metals in plant tissue allows significant advances in phytoremediation studies as well as in other aspects of environmental sciences (Mera *et al.*, 2019). Rawlins *et al.* (2016) studied the three-dimensional soil organic matter distribution using Osmium staining (OsO_4) and synchrotron X-ray computed tomography.

Information at the molecular level is important for a better understanding of the chemical and biological processes affecting speciation, properties, and behaviour of contaminants, pollutants, and nutrients in the ecosphere. In this context, a growing need for micro-spectroscopy and imaging facilities using SR sources can be envisioned.

References

Abdollahi, L. and Munkholm, L. J. 2014. Tillage system and cover crop effects on soil quality: pore characteristics. *Soil Sci. Soc. Am. J*. 78:218-226.

Balerna, A. and Mobilio, S. 2015. *Synchrotron Radiations: Basics, Methods and Applications.* Springer, Germany, pp. 3-27.

Koebernick, N., Daly, K. R., Keyes, S. D., George, T. S., Brown, L. K., Raffan, A., Cooper, L. J., Naveed, M., Bengough, A. G., Sinclair, I. and Hallett, P. D. 2017. High-resolution synchrotron imaging shows that root hairs influence rhizosphere soil structure formation. *New Phytologist* 216(1), pp.124-135.

Lombi, E. and Susini, J. 2009. Synchrotron-based techniques for plant and soil science: opportunities, challenges and future perspectives. *Plant Soil* 320:1-35.

Mera, M. F., Rubio, M., Perez, C. A., Cazon, S., Merlo, M. and Munoz, S. E. 2019. SR induced micro-XRF for studying the spatial distribution of Pb in plants used for soil phytoremediation. *Radiation Physics and Chemistry*, 154: 69-73.

Rawlins, B. G., Wragg, J., Reinhard, C., Atwood, R. C., Houston, A., Lark, R. M., and Rudolph, S. 2016. Three-dimensional soil organic matter distribution, accessibility and microbial respiration in macro aggregates using Osmium staining and synchrotron X-ray computed tomography. *Soil 2*(4): 659-671.

Yang, J., Liu, J., Dynes, J. J., Peak, D., Regier, T., Wang, J., Zhu, S., Shi, J., and John, S. T. 2014. Speciation and distribution of copper in a mining soil using multiple synchrotron-based bulk and microscopic techniques. *Environmental Science and Pollution Research*, 21(4): 2943-2954.

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