Neutron imaging of plant-soil systems at the Oak Ridge National Laboratory

Spallation Neutron Source

High Flux Isotope Reactor

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PRINCIPLE OF NEUTRON IMAGING

The principle of neutron imaging is based on the attenuation, both scattering and absorption, of a directional neutron beam by the material through which it passes. Neutron imaging has been shown to provide non-destructive, complementary capabilities to current X-ray imaging. X-rays are scattered and absorbed by the electrons, so attenuation increase monotonically with atomic number. Neutrons, on the other hand, interact with nuclei and their scattering and absorption powers do not scale in any regular way with elemental mass. Since neutrons strongly scatter H atoms, biological sciences materials such as plants are prime candidates for neutron imaging.

Neutron imaging provides non-destructive, non invasive, real-time, quantitative *in situ* measurements of soil, roots and plant systems to:

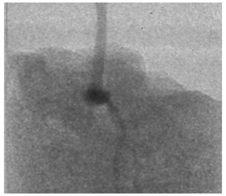
- quantify plant ontogeny and phenology related to genetic or environmental stimuli root morphological development
- resolve biological and biogeochemical flux dynamics within and between soil, plants and microbes
- identify interactions between biotic and environmental components

POTENTIAL AVENUES OF RESEARCH

- **plant or rhizosphere water dynamics,**
- **root morphological development,**
- **transport of chemicals or plant growth regulators in roots and between plant tissues,**
- **dynamics of plant-stress or plant-pathogen response.**

Flux of H_2O and other compounds can be achieved through manipulation of the ratio of H_2O:D_2O within the system, or by labeling specific compounds of interest with elements that have distinctive scattering or absorption properties (e.g., H, D, Li, B or Gd).

Neutron imaging may provide quantitative, non-destructive, real-time, in situ images of soil, root and plant systems, interactions and processes



Neutron radiograph of a single switchgrass plant - leaf blade, seed and root system are visible.

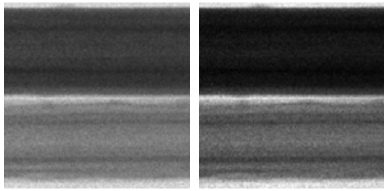
METHODS

- Chambers constructed from Al cylinders (max 10 cm) or thin plates.
- Fine sand (SiO_2) used as the primary component of the soil (50+%)
- Al and SiO_2 have little impact of neutron beam attenuation.
- Poplar tree cuttings, switchgrass (far left) and maize (left) were successfully cultivated in the chambers with 50% D_2O to enhance contrast of added H_2O pulses.

RESULTS (wood tissue)

- Neutron wavelength selectivity enhances contrast to distinguish water content.
- (right) Stem segments from grape vine imaged at SNS SNAP beam line.
- Moist (top) or partially-dry (bottom).
- Better contrast was achieved using lower energy neutron wavelengths.

Neutron Wavelength Selection
0.3 – 1.0 Å 3 – 4 Å



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ORNL FACILITIES - Reactor and Accelerator-based Neutron Imaging

- A neutron imaging program has been initiated at the Spallation Neutron Source (SNS) at Oak Ridge National Lab.
- Preliminary neutron imaging experiments were conducted in 2008 on soil and plant samples at the SNS SNAP diffractometer beam line.
- Experiments will continue at the High Flux Isotope Reactor (HFIR) using a monochromatic development beam line.

SNS-SNAP imaging in Fall, 2008 was performed in conjunction with Anton Tremsin, Space Sciences Laboratory, University of California - Berkeley

Recent Funding through ORNL Laboratory Directed Research and Development Program:
(2010) Neutron Imaging of Fluid Flow Dynamics within Plant-Soil-Groundwater Systems. PIs: H. Bilheux, J. Horita, J. Warren, E. Perfect (UT-Knoxville)
(2008) In Situ Neutron Imaging of Roots and Rhizosphere Water Exchange. PIs: S. Wullschleger, J. Warren, H. Bilheux

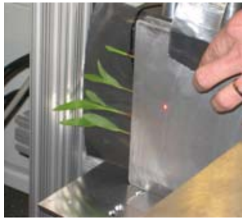
Relevant references:
Anderson, IA, McGreevy, RL & Bilheux HZ, eds (2009) Neutron Imaging and Applications. Series: Neutron Scattering Applications and Techniques. Springer.
Nagarkar, VV, et al. (2007). "Time-Resolved High Resolution Neutron Imaging Studies at the ORNL SNS." Session N14-4, IEEE Trans. Nucl. Sci.

ORNL NEUTRON IMAGING	Current HFIR development beam line	Proposed (VENUS) SNS beam line
Neutron wavelength	Cold	Epithermal, Thermal, Cold
L/D	200 - 1000	150 - 1500
Spatial resolution	~ 50 microns	~ 10 microns
Field of view	~ 8 x 8 cm	~ 20 cm x 20 cm
Translation-Rotation Stage	30 cm diameter (40 kg max)	2 m x 2 m (2 ton max)
Detector	CCD	CCD, EMCCD, MCP
Sample storage	Next to beam lines	Integrated
Data Storage	Portable HD/ORNL	Portable HD/ORNL
Data Analysis	Octopus/Amira	Octopus/Amira Development

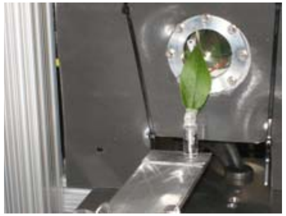
RESULTS (Leaf tissue)

Initial neutron imaging of plants was successfully conducted at SNS beam line 3 (SNAP) in 2008 using a 1.7 cm^2 experimental UC Berkeley detector system (with A. Tremsin). Neutron imaging successfully distinguished between non-deuterated or deuterated poplar leaf samples. Fine leaf veins (<200 um) are readily visible in the non-deuterated sample (below center-right), in comparison to the deuterated sample (below far-right). This difference in contrast establishes the potential for tracking a pulse of water through the soil-plant system.

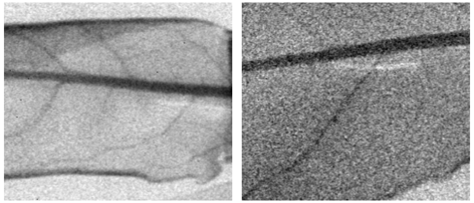
[scale: 17 x 17 mm]



Imaging the soil-root system of maize seedlings at SNS SNAP



Imaging a deuterated poplar leaf using an MCP detector at SNS SNAP



H_2O D_2O

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