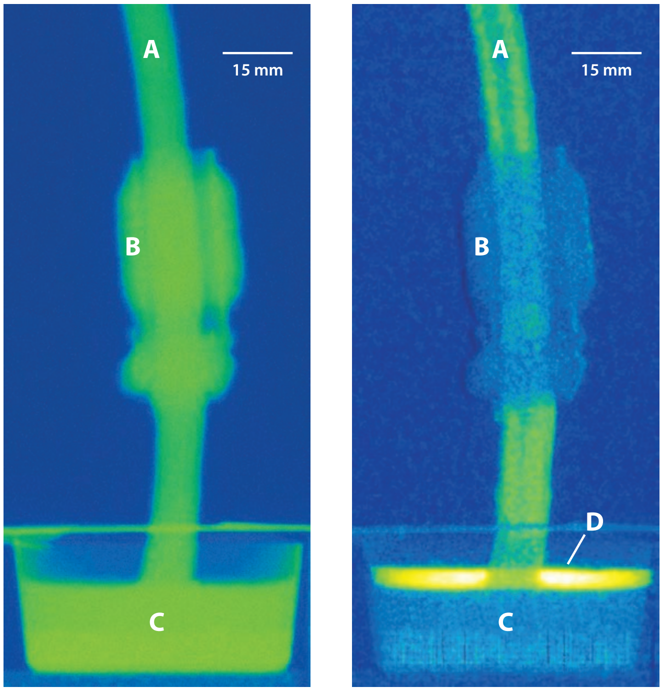
SPOTLIGHTS

Diagnosis: Drought

GLOBALLY, DROUGHTS ARE BECOMING MORE FREQUENT and more severe. Because the availability of water controls a plant's ability to exchange gas with the atmosphere, taking in carbon dioxide and releasing oxygen—both processes that humans rely on plants to do—scientists need to understand how different kinds of plants respond to drought. That means they need instruments that can measure water in plants over long periods of time. However, most methods in use today involve puncturing the plant and probing the inside, which damages the plant and creates confounding dryness at the site being measured. There aren't many options for objective, non-destructive, low-cost, lightweight, and scalable water measurement in the field.

Nuclear magnetic resonance (NMR) is the leading technology for non-destructively measuring plant water content (though it misses most of the other marks above). NMR is not an imaging tool, but it can measure the total amount of hydrogen atoms in a given section of tree trunk or branch. The technique relies on the magnetic properties of hydrogen nuclei: When placed in a magnetic field, the hydrogen nuclei align themselves with the field according to their magnetic spin properties. In this stage, the nuclei absorb energy from electromagnetic radiation. When the magnetic field is removed, the nuclei return to their normal, unaligned state, and emit the absorbed energy at a specific resonance frequency. (NMR can be tuned to measure different elements, each of which has its own resonance frequency.) The energy emitted by the hydrogen atoms, when compared to previous measurements, reveals whether there were any changes in the hydrogen content of the sample. More hydrogen generally means more water.



Neutron images of a tree branch before and after taking up heavy water. (Left) A tree branch (A) is shown with the NMR device (B) wrapped around it and standing in a vessel of heavy water (C) after having first taken up normal water. (Right) Subtracting subsequent neutron images from the first image creates a picture of water transport and reveals how much (and how quickly) the heavy water is taken up by the branch (D). The bright green regions in the image on the right are the areas of greatest difference from the image on the left.

The drawbacks to traditional NMR come from its dependence on a large magnetic field for high-resolution measurement, which can only come from heavy and costly permanent magnets that interfere with other instrumentation and require the work to be confined to a laboratory. Los Alamos scientist Sanna Sevanto and her colleagues have developed a radically different approach to measuring water uptake and transport in living plants that avoids permanent magnets entirely and relies on comparatively miniscule magnetic fields. An adaptation of ultra-low magnetic field technology pioneered at the Laboratory by scientists Michelle Espy and Michael Malone for medical magnetic resonance imaging (MRI), the new plant NMR system consists of an air-cored electromagnet operating at an ultra-low field strength (about a million times weaker than a conventional hospital MRI).

The setup provides a number of advantages over conventional NMR or other techniques. First, because it's an electromagnet—created basically by coiling an insulated current-carrying wire around the tree trunk—it is affordable, lightweight, and easily adapted to trees of different sizes. Second, because the magnetic field is so weak, the scientists can use other instruments in tandem, and the NMR electromagnet won't interfere. Third, it provides more complete data than the usual invasive techniques because it allows water measurement from the entire cross section of a tree. And last, because of the reduced interference, modest price tag, and small size, multiple systems can be set up within the same study area, or even on different parts of the same tree, which enables more comprehensive study of the drought response.

To test their setup, Sevanto and her colleagues did a variety of experiments in a greenhouse setting. They were able to distinguish rates of water transport clearly in four different types of trees, across a twenty-degree temperature range, during a two-month period of peak drought season. They also experimentally mimicked naturally occurring extreme conditions that alter trees' water content and were able to detect changes on a time scale as short as 30 minutes.

To confirm that the NMR measurement was actually measuring water transport through the plants' conduits and not the water inside the plants' cells, the scientists needed to validate the NMR findings with an imaging method. For this, the team conducted neutron imaging at the Los Alamos Neutron Science Center. Because it wasn't practical to bring whole trees into the facility, they used freshly cut branches, which can still transport water.

The branches were first given normal water and then switched to heavy water (H_2O in which the hydrogen atoms have an extra neutron) just before being placed in the neutron beam. Whereas normal water tends to stop neutrons from passing through the tree branch to detectors on the other side, heavy water does not. So as the normal water was displaced by the heavy water entering the tree branch, the images of the branch gradually changed from fairly dark (opaque to neutrons) to much more transparent. Conveniently, NMR can also distinguish between normal and heavy water, so the researchers conducted NMR simultaneously with the neutron imaging. By comparing neutron imaging and NMR data, they were able to conclude that the NMR technique was indeed capturing water transport within conduits, not water inside cells.

"There are two branches to what we're doing," explains Sevanto. "There's the new technology—developing low-field NMR to look at trees in nature—and then there's the new kinds of data we're getting. If we understand both things as thoroughly as possible, we will be able to combine the new technique and new data with others' studies and really improve the state of drought science moving forward." LDRD

—*Eleanor Hutterer*

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From Cosmos to Canyons

HERE'S THE PROBLEM: YOU'VE GOT A NATURAL LANDSCAPE with the possibility of past exposure to chemical or nuclear contamination, and you want to keep a watchful eye for contaminants that could discharge to a major river system through storm-water runoff. It's a rugged, remote, and expansive region, with few roads and no electricity, and you're going to need to monitor it continuously, rain or shine, for years. How do you do it?

You could try to design from scratch a versatile network of a hundred or more low-power sensors that operate reliably in variable weather conditions using a robust data-transmission system to send the measurement data from remote locations without line of sight to any kind of receiver. Or you could call someone accustomed to handling that kind of thing.

That's how it went down when Armand Groffman and Steve Veenis, environmental science specialists from the Lab's Surface Water Program, met with Janette Frigo of the Laboratory's Space Data Science and Systems group. Groffman and Veenis wanted to monitor