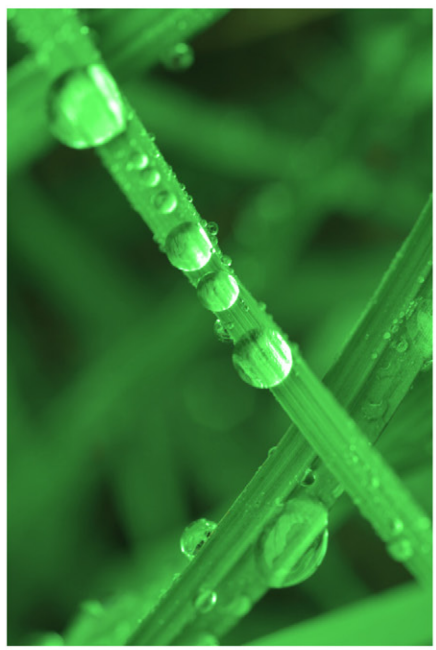
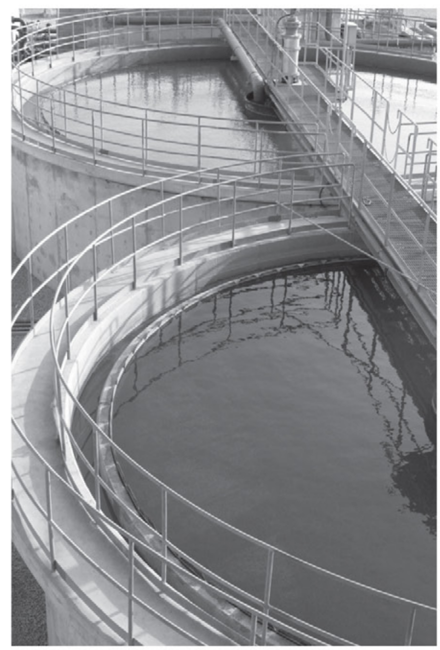
Three Shades of Water

Increasing Water Security with Blue, Green, and Gray Water

by Caroline Schneider

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One of the most precious resources on earth is dwindling, and its decline affects the lives of everyone on earth. Its scarcity is economically, biologically, and ecologically costly. It's not oil, but a resource even more precious—water.

But water is everywhere. We must have plenty, right? Not at all, says ASA and SSSA member Henry Lin, professor at Pennsylvania State University. "If a beer barrel—13 gallons—represents all of the water on earth, the total amount of fresh water is just 10 drops. Not only that, but out of that 10 drops, only one-tenth of one drop is in surface water that we can see and directly access."

With the limited amount of water around the world and the increasing number of people depending on it, water security is tenuous. The population is expected to be about nine billion people by 2050, and estimates show that food production will need to increase by about 70% in that time to meet demands. With 17% of cropland being irrigated, and that irrigated land producing 40% of the food, water resources will become more strained. Competition from industry, urbanization, and recreation along with continuing pollution, climate change, and distribution problems will greatly test water resources.

But there are solutions. Integrated water management plans using "blue," "green," and "gray" water can increase water security throughout the world. So what do these colors mean, and what are these precious waters that are vital in a changing world with a growing population?

Blue Water

Blue water is found in lakes, rivers, and reservoirs, or pumped from aquifers. Available blue water is used for many purposes including drinking water, water for homes and businesses, and irrigation water for agriculture.

"Blue water is what we can directly tap into for drinking and irrigation," Lin says. "It is very critical."

Because of our dependence on blue water for multiple uses, its scarcity causes concern. As the human population grows, we're using more and more water for drinking, home use, and industrial purposes. We also need more food, which requires huge amounts of water to produce. In fact, irrigated agriculture uses about 70% of the blue water withdrawn globally. And the increased demand for water and food is just the start of how humans affect blue water supplies.

As more people move to cities, they build and pave over the soil. But it is through that soil that precipitation travels to replenish groundwater stores. Without refilling those stores, we risk losing the source of water from which we can draw for drinking or irrigation.

"We tend to seal up the ground," Lin explains. "We need to plan so that we don't block the critical recharge areas for groundwater. We can even enhance recharge through appropriate planning."

Blue water is found in lakes, rivers, and reservoirs, or pumped from aquifers. It's used for many purposes including drinking water, water for homes and businesses, and irrigation water for agriculture.

In addition to blocking groundwater recharge, urbanization and human development also leads to pollution and climate change. Pollutants, such as fertilizers, detergents, or trash, decrease blue water quality, and climate change greatly affects the lakes and rivers around the world, in turn disturbing people who live near them.

A striking example of the number of people that can be affected by changes in water resources is found in the Himalayas. Eleven major rivers run through the Himalayan region. The glaciers from which the rivers originate are melting very quickly.

"If that water supply becomes seasonal or there are flash floods or droughts, all the people living in the region will be affected," explains ASA and SSSA Fellow Rattan Lal, professor at The Ohio State University. "There

Image courtesy of USDA-NRCS Texas

are 2.4 billion people in that area. That's one-third of the world population."

To protect blue water and increase water security, scientists, economists, agronomists, and others are working together to integrate green and gray water resources. For many in the agronomy, crop, and soil fields, the key to water security is deceivingly simple: increase green water. But how do we do that?

Green Water

Green water is the water available in the soil for plants and soil microorganisms. It is the water absorbed by roots, used by plants, and released back to the atmosphere through the process of transpiration. Green water can also leave the soil through evaporation or subsurface runoff, but it is considered productive only when it is used for plant transpiration. "The green water that is transpired is what increases the plant yield," explains Bob Stewart, professor at West Texas A&M University.

Various factors determine how much water is needed for a plant to grow: how hot it is, how sunny it is, how windy it is, and how dry the air is. These factors change the amount of green water a crop needs, and therefore how much irrigation might be needed in addition to the rainfall in an area. The overall goal is to get more crop per drop of water and decrease the need for irrigation.

Before water can be used to produce crops, it can be lost in several ways—through percolation deep into soil beyond the plant roots, evaporation, and runoff. Finding ways to minimize these losses, such as through management practices, will maximize the amount of water available for transpiration. "If you look at precipitation, only 15–30% will be used for transpiration," Stewart says. "But 30–50% will be lost as evaporation, and 10–25% will be lost as runoff."

Green water is the water available in the soil for plants and soil microbes. It is absorbed by roots, used by plants, and released back to the atmosphere through transpiration.

Cover crops can shade the soil and decrease water loss from the soil surface. Likewise, no-till practices leave crop residue on the soil and prevent evaporation. Cover crops and no-till practices also prevent soil erosion and runoff by holding soils in place and encouraging water to soak into the soil instead of skimming off the surface.

These practices also increase soil quality— a factor that greatly affects water storage and use. In fact, Lal says, "Soil quality determines water use efficiency." Cover crops and no-till increase the amount of organic matter present in the soil. Organic matter promotes a healthier soil with more soil aggregates and pores. This structure helps the soil retain water. Additionally, earthworms like soils with higher organic content, and their burrowing can increase the number of pores in the soil where water can infiltrate.

Organic matter also affects water quality by altering the microorganisms in the soil that break down materials in water. When water, nutrients, and chemicals are applied to crops growing in soils with low organic content, the soil can't hold the chemicals and nutrients. Instead, they are leaked into groundwater, which people drink, or they reach surface waters where they cause algal blooms and decrease water quality.

"Soil that is not healthy has inadequate microbial activity," Lal explains. "But healthy soils can hold those chemicals, and the microbes break them down before they get into the water or air."

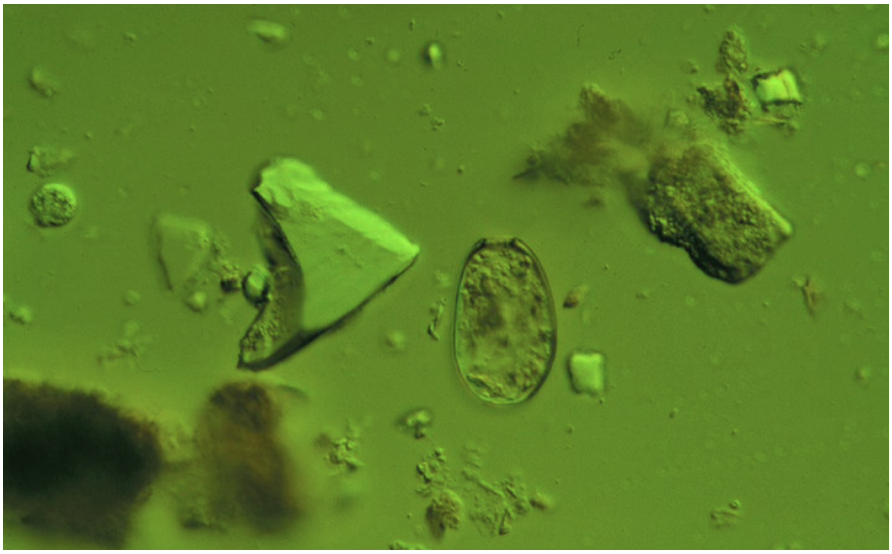


Image courtesy of: Soil and Water Conservation Society (SWCS). 2000. Soil Biology Primer. Rev. ed. Ankeny, IA: Soil and Water Conservation Society.

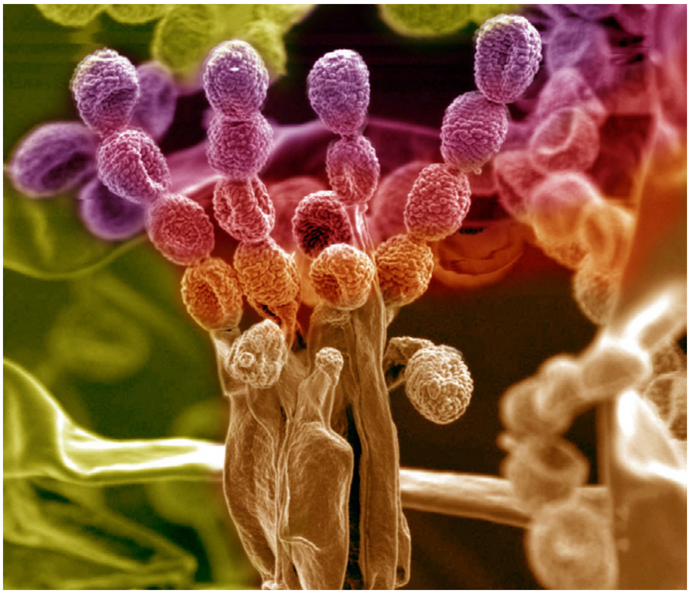
Maximizing Green Water through Rhizospheres and Plant–Soil Feedbacks

With estimates of the world population reaching nine billion by 2050, an increase in food production will become vital. There are limited options for expanding crop production for a growing population, though. Both land available for conversion to fields and freshwater available for irrigation are dwindling. But there is a resource that holds promise for agriculture—green water, the water in soil potentially available to plants.

To be used by plants, green water must pass through the rhizosphere, the region of soil found close to and influenced by roots. A paper published online recently in *Vadose Zone Journal*[1] describes how rhizospheres and positive plant–soil feedbacks can lead to more efficient use of green water, a sometimes overlooked resource for crops.

"Nearly 90% of the water consumptively used by croplands worldwide is green water, and green water sustains the terrestrial ecosystems of the world," says SSSA Fellow Garrison Sposito, professor at the University of California–Berkeley and author of the paper. "All the public attention in the past has been paid to the charismatic blue water, the freshwater flowing in rivers and in groundwater aquifers, while green water has been its 'Cinderella,' quietly doing the world's work without fanfare."

Of the green water available to plants, as little as 30% is used for transpiration under some conditions. The rest may be lost through evaporation or subsurface runoff. Transpiration is termed "productive green water flow" since water used for transpiration leads to plant growth. If 85% of available green water could be used for transpiration, and therefore become productive, crop yields could as much as triple.



Spores of a soil fungus that associates with plant roots, microbial biofilms, and soil minerals. *Flickr/Pacific Northwest National Laboratory.*

A plant–soil feedback loop could lead to more productive green water use, Sposito says. Healthy soils with plenty of nutrients lead to healthy plant root systems that will use more water for transpiration than smaller roots. These plants will grow larger and create lush canopies that provide shade and decrease evaporation from the soil. More green water is then available for transpiration and can be used to stimulate more crop growth.

Beneficial microorganisms regulate key processes that also aid crop growth, such as the transformation of organic matter into plant nutrients. Within the rhizosphere, those microbes are especially abundant. A synergistic relationship between plant roots and microbes is necessary for healthy plants and increased plant biomass. Additionally, roots can produce a mixture of organic compounds called mucilage. Mucilage stimulates the soil microbes and increases the water-holding capacity of the soil, making more water available to plant roots.

Therefore, cultivating plants that establish rhizospheres with beneficial microbes can impact water availability and crop production. "Plant roots can drive the biological evolution of soil microorganisms," Sposito says. "We can direct this evolution by developing crops that enhance the beneficial functions of microbes within the rhizosphere."

Researchers are currently finding ways to capitalize on plant–soil interactions and the soil microorganisms in the rhizosphere. That work is a key ingredient in the recipe for better utilizing available water and securing resources for expanding crop productions. As blue water availability decreases, Sposito and others in the field feel that now is the time for the Cinderella of freshwater—green water—to take its place in the spotlight.

[1] See www.soils.org/publications/vzj/view/first-look/v13-02-0041.pdf

Beyond traditional management practices, new techniques are also being studied in an effort to use green water efficiently. All green water used to produce crops must pass through the rhizosphere, the region of soil directly around and influenced by plant roots. A rhizosphere that contains productive microorganisms and healthy roots can increase crop yield and the ability of the soil to hold water. Scientists are currently researching ways to breed plants that would encourage a healthy soil environment and rhizosphere. (See sidebar on page 7 for more information.)

The amount of global green water flow through plant transpiration alone is greater than the flow in all rivers going to the ocean. This resource creates an obvious opportunity. By conserving green water and improving soil quality, areas that currently see low yields can produce more crops with the water they have.

Gray Water

To supplement green water, agronomists and scientists are looking to gray water. The term is typically applied to water that has been previously used and may contain some impurities. Gray water has been used by cities, households, and industries. It is the wastewater that is usually treated and discharged.

"Nature made blue and green water," Lal says. "Humans came in and made it gray. That's colored by humans."

Even though it's a product of humans, the idea of reusing gray water might make people cringe. But despite what some may think, even a fresh glass of water has been used many times before. The water has gone around the hydrologic cycle again and again over millions of years.

"A dinosaur may have drunk that same drop of water millions of years ago that you're drinking now," explains Steel Maloney, president of Cascade Earth Services. "We have to back away from our perceptions that water is pure and we're the only ones that have ever touched it."

But how much gray water can there be from people washing their hands, cleaning their vegetables, or spraying down their driveways? There is actually a lot of gray water out there. On top of household wastewater, industries produce a significant amount of gray water in their operations.

"A large vegetable-processing plant consumes as much water as a city of 100,000 people," Maloney points out. "And in many areas, power production will use as much water as irrigated agriculture."

Gray water

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The amount of gray water will only increase as the population grows and there are more people to consume energy, wash their hands, and eat food prepared by processing plants. The USEPA estimates that by 2025, wastewater inflows will be around 52 trillion gallons per day. That volume of water hypothetically could provide enough green water for 20 million acres of land.

"If we change nothing else except that we start reusing water rather than throwing it away, we could put another 150,000 or so fields into production," Maloney predicts.

That reuse not only creates more green water for plants, but it also saves blue water while providing multiple other benefits. Reusing gray water can actually decrease energy consumption—by up to 80% Maloney estimates. Because the water has already been pumped from the ground, additional energy that would be used to pull out more blue water is saved.

Also, while some treatment of gray water is needed, it doesn't have to be treated to a pristine level. Sufficiently treated water can be put on a field,

Image courtesy of iStockphoto.com/DmitriMaruta.

and healthy soil will then finish the treatment by filtering it and removing chemicals. As with green water, the quality of the soil is an important factor in gray water reuse.

"Soil is simply an amazing medium," Maloney says. "If we take care of it, it can regenerate just about any water quality."

Another benefit of gray water reuse is nutrient recycling. While the water is treated, it still contains significant amounts of nutrients that are needed by the crops. When water is put back onto soil, the remaining nutrients go with it. Recycling those nutrients not only helps build crop yields, but it also means the nutrients stay out of surface waters and groundwater where they might otherwise affect water quality.

It is critical to know what you're putting on the land when reusing gray water. The first known environmental problem was seen in the Fertile Crescent. Soils in the area of Mesopotamia became salinized through poor irrigation practices, and interestingly, this is documented in tax records. Both wheat, a crop that poorly tolerates salt, and barley, which is more salt tolerant, were grown in the area. Tax records show that over several centuries, there was a switch from growing wheat to growing barley to adapt to the saltier soils.

"Over several hundred years, cropping patterns changed due to the use, or I should say misuse, of irrigation water," explains Certified Crop Adviser and ASA member Fred Vocasek, agronomist at Servi-Tech Laboratories.

Regulations surrounding gray water are now in place to avoid such misuses. Almost all gray water is regulated to some degree. The National Pollution Discharge Elimination System is a federal permit system administered by the states. Virtually any municipality, processing plant, or industry that discharges wastewater has a permit, and each permit is written for the specific site. Those customized plans are dictated by the contaminants.

Interested in this topic? Check out this symposium at next month's Annual Meetings in Tampa:

At the Annual Meetings next month, on Tuesday, 5 November from 1:15–4:45 pm, there will be a symposium titled "Blue Waves, Green Dreams, and Shades Of Gray: Perspectives On Water." It will take place in the Tampa Convention Center, Ballroom B-D. For more info, see http://scisoc.confex.com/crops/2013am/webprogram/Session11697.html.

"The regulations might be written for various things—pathogens, organic materials, nutrients, metals—depending on the water," Vocasek says. "After all, the idea is to avoid degradation of both the land and the water."

There are currently thousands of projects around the globe in which gray water is being used successfully to irrigate fields. In Dodge City, KS, where Vocasek works, the beef-processing plant and the city jointly use a wastewater treatment facility. Since 1986, that gray water has been used to irrigate about 3,000 acres of land.

Maloney has worked on many gray water projects throughout the world. A large municipality in the United States is reusing its wastewater to irrigate 2,100 acres on which grain and alfalfa grow. Farmers are yielding about 12 to 14 tons of crops per acre, and about 3.6 million gallons of water is recycled each year.

In another area, wastewater from an industrial park is being reused to irrigate around 1,800 acres of corn and potatoes. About 680 million gallons of water are reused per year here, and the project has been so successful that other industries are asking to move to the area to be part of the reuse system.

"Gray water has to be part of the green water solution," Maloney says. "Its reuse reduces treatment costs, nutrient input to surface water, blue water withdrawals, and power consumption. It will expand agriculture, and fields that weren't farmed can come into production because this water is available."

The Future of Water Security

Water is a vital part of human life, and our food supply, among other necessities, depends on water security. Increasing the amount of green water available to crops and the efficiency with which the plants use it are necessary to secure food for a growing population. The reuse of gray water is essential too. Gray water reduces the use of blue water and provides additional green water while lowering energy costs and recycling nutrients.

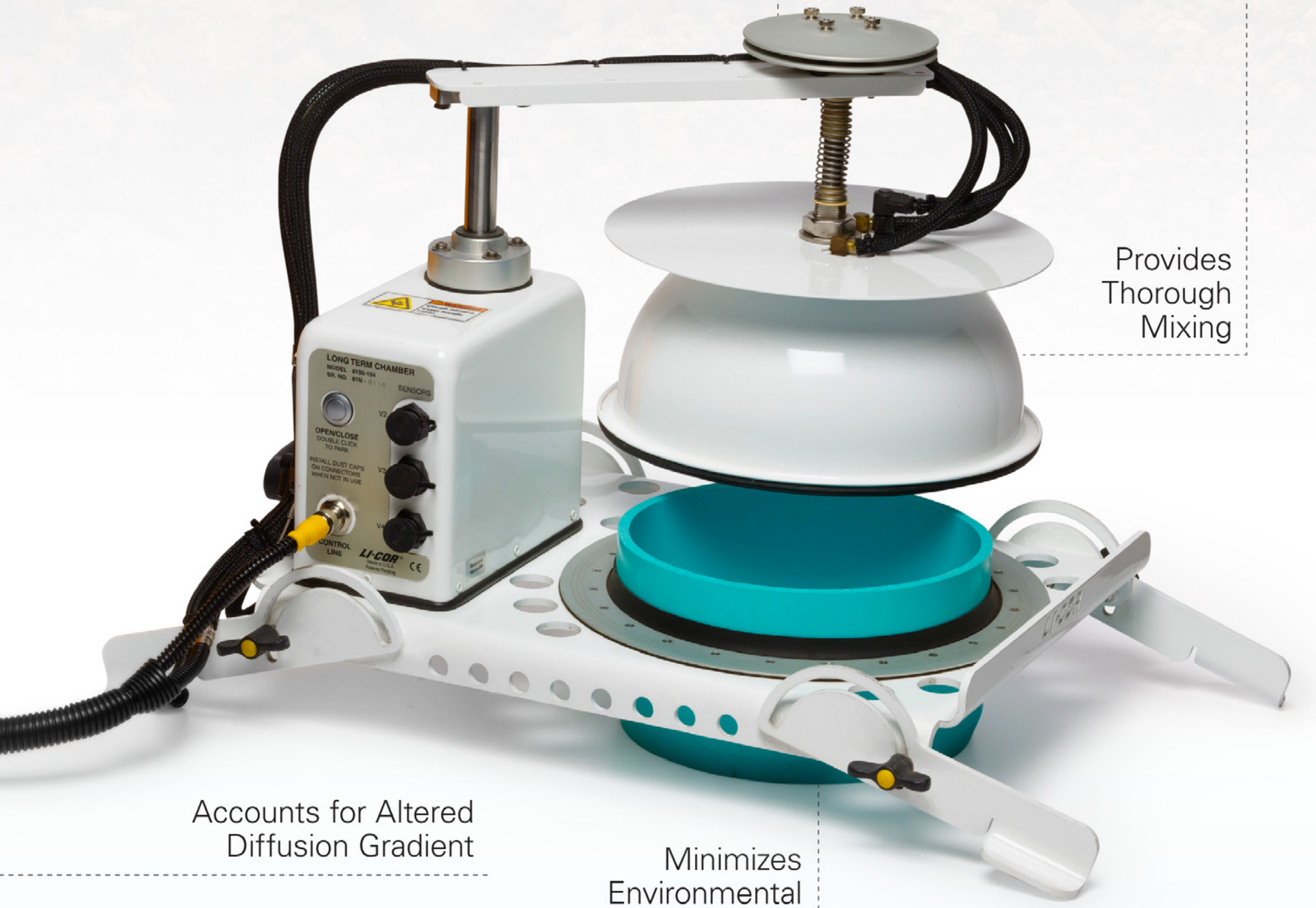
The water footprint also has to be considered as we look for ways to preserve water. A water footprint is the amount of blue, green, and gray water contained in and used to produce a food item. That amount varies widely in different foods. For example, a pound of beef requires about 10 times as much water to produce as a pound of wheat.

"How much do we value a crop versus the water used to produce it?" Lal asks. "This is an important part of the water security discussion."

That discussion has to continue if we are to find solutions to the inevitable shortage of water our growing population will face. With only 10 drops of fresh water out of a full barrel of water on earth, we have to protect, reuse, and respect those few drops. "Water resources are going to be more precious in the future than the oil resources are," Lal says. "There are substitutes for oil, whether it's nuclear, geothermal, solar, or wind energy. There is no substitute for water."

C. Schneider, Science Writer for ASA, CSSA, and SSSA

We've addressed the critical considerations for making soil flux measurements.



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