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Grasses are spendthrifts, forests are budgeters, in a nuanced account of plant water use

Even a toddler knows that plants need water. It's perhaps the first thing we learn about these green lifeforms. But how plants budget this resource varies considerably. The kapok trees of the Amazon have adopted vastly different strategies than the switchgrass of the American plains. Unfortunately, it's hard to directly measure which ones prevail in different ecosystem types and how they shift under changing conditions.

Researchers at UC Santa Barbara and San Diego State University recently developed a metric for detecting these behaviors from soil moisture data. Now they've applied the model to a global dataset of soil moisture levels. The results, published in Nature Ecology & Evolution, reveal that aridity and vegetation density drive the way that plants approach water management. The research was supported by a grant to UCSB from the Zegar Family Foundation.

"When plants face water shortages, grasslands act like spendthrifts (using water aggressively until it's gone). In contrast, forests act more like careful budgeters (cutting back water use early to avoid disaster)," said senior author Kelly Caylor, a professor at UCSB's Bren School of Environmental Science & Management. The paper also suggests that current models probably overestimate how fast ecosystems lose water during droughts.

The ramifications go beyond intellectual curiosity; the interplay between plant behavior and soil moisture forms an important part of climate models. Understanding these dynamics can inform our own water management, agricultural activities and climate resilience.

A different perspective

Plants have evolved many ways to respond to water stress, reflecting the diversity of the kingdom and the ecosystems they live in. But researchers haven't been able to find any patterns in these behaviors across different ecosystem types. Lead author Bryn Morgan realized that the relationship between vegetation and soil moisture could illuminate plant behavior.

Biologists, geographers and earth scientists all want to understand how soils dry out. This process impacts ecosystem productivity, climate trends and global processes like the carbon and water cycles. Standard models of soil drydown focus more on numerical simplicity than on tapping into plant transpiration dynamics. They treat the interaction between plants and soil moisture as a simple, linear relationship.

“But there is nonlinearity in the data,” said co-author Ryoko Araki, a joint doctoral student at UCSB and SDSU. Plants adopt different approaches to using water based on climate, soil moisture and their life history. And plants can also adjust their strategies as conditions around them change.

To address this lacuna, Araki led the development of a nonlinear model describing how soil dries after rain. The result is a more accurate framework that captures factors neglected by linear models. The new, nonlinear parameter in the model reflects how much risk plants are willing to take under water limitation.

Now the researchers could explore these behaviors in greater depth. “We wanted to know what's the stereotypical behavior of these vegetation types?” said lead author Bryn Morgan, a postdoctoral fellow at MIT who led the study as a doctoral student at UCSB.

Morgan and her co-authors applied the new model to soil moisture data from a global network of in-situ instruments. They identified stretches of time when the soil was drying out, fitting their model to each episode individually. By analyzing the slope and shape of the curve, they could investigate the behaviors of different vegetation types.

From the mountains to the prairies

Plants in grasslands and arid regions adopt more aggressive strategies overall, the authors found. In contrast, plants tend to adopt more conservative strategies in more humid and more woody areas like forests and woodlands.

“If water is the currency of vegetated ecosystems, grasses are out here like, ‘YOLO,’” Morgan said, “while trees are investing for retirement. They’re playing the long game.” Grasses and herbaceous plants often complete their entire lifecycle in a single year, so there’s little benefit to playing it safe when water is scarce. Meanwhile, trees need to adopt a more cautious strategy, so they’ll take precautions to avoid damaging their vascular tissues.

You can also compare the plant communities to different kinds of athletes. “Grasslands are like sprinters who give everything they have until they hit the wall,” Caylor explained. “Forests are like marathon runners who pace themselves and slow down strategically to finish a longer race.”

“This is the overall behavior,” Morgan added, “but, of course, we see a range of aggressive to conservative strategies within a given ecosystem.”

With an understanding of how behaviors differ between vegetation types, the authors turned their attention to variability within ecosystems. One by one, they examined how water-use strategies shifted in grasslands, savannas and woodlands as conditions changed.

Image

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Different plants live life at different paces, which is reflected in how they use water.

The team found that, as an area becomes drier or water demand from other plants increases, the plants in that area shift toward more aggressive water-use strategies. For instance, plants in a strongly seasonal area, like the Mojave Desert, will shift their strategies dramatically over the course of the year. This, in turn, influences the ecosystem's character.

Until now, scientists have studied water-use strategies either at very fine scales in the lab or at the landscape scale using remote sensing. "Bryn's approach is clever in using in-situ measurements at a global scale," Araki said. This combination uncovered patterns that were previously hidden.

Zooming out

Soil moisture appears in larger earth systems models, but often without the nuances of plant behavior. "The uncertainty in estimates of the global carbon cycle is really sensitive to how vegetation responds to soil moisture limitation," Morgan said. Understanding the dynamics between plants and soil moisture should improve these models.

Morgan plans to investigate how soil moisture and plant water use affect the Earth's water and carbon cycles. She has submitted a proposal to NASA for three years of funding to look at how the team's nonlinear parameter is represented in current earth systems models. She also plans to continue investigating how this variable shifts over time and the feedback loops involved.

Araki has turned her focus toward issues of extrapolation. Soil moisture varies widely across a landscape, making it difficult to scale measurements up or down. Geostatistical approaches have failed because landscapes are neither smooth nor completely random. "In reality there is topography, vegetation, soil," she explained, so scientists can't apply simple statistics to the system.

"Understanding how soil moisture values themselves scale is something hydrologists have been interested in for decades," Morgan added. So the search is on for laws or behaviors that can explain how this property scales from a point to a watershed.

Models are always a simplification of the system they describe — tools for exploring relationships. There are always tradeoffs, the authors acknowledged, and sometimes scientists must gloss over certain details to create something useful. But even a toddler can tell there’s a difference between a forest and a grassland, and finally we have a model that takes this to heart.

Tags

Climate Change

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