From plant anatomy to ecology: A model that resolves multiple scales

Of all the rain that falls on land, plants use more than ninety percent of it for their various needs, especially photosynthesis. Therefore, to predict worldwide shifts in climate, agricultural yield and forest productivity, it is paramount that we understand plant water use and how it might adapt.

Over the past century, with the advent of powerful microscopes, CT and MRI scanners, research lead to increasing knowledge on plant anatomy (see professor Craig Brodersen’s lab work at Yale University). In this context, plant anatomy refers to the properties of the thousands of conduits (or tubes) in a plant, and the connections between the conduits, that offer water a pathway from the soil to the leaves. These conduits and their respective common walls (connections) have diameters sized at micro-meter to nano-meter scales, respectively. Despite their diminutive dimensions, these anatomical elements are responsible for gallons of water supplied to the leaves a day. However, characteristics such as size and the positioning of conduits relative to each other (called topology) also determine how the whole plant adapts to changing rainfall patterns including drought. As drought proceeds, the plant is less efficient in supplying leaf water and could die as a result. It is this reduction in water transport that is sought after through the lens of plant anatomy.

Plant ecology is a broad field of study that includes how a plant or a collection of plants take advantage of their environment and respond to its long term alterations. Much of plant ecology is driven by plant water use. If we are to understand the effects of changes in climate on our long term livelihoods, we need to step up our understanding of plant ecology. In this study, we develop a computer program (or model) that allows going from information at the anatomical level of plants to their overall water use, we call this practice, going from small elements to the collective, up-scaling. With this program, we are hoping to answer the following: how does the geometry of the conduits, including their length and girth as well as their positions relative to each other, affects how resilient different plants are to extended periods of called droughts and therefore, its effect on plant ecology.

The purpose of any computer model of a natural system is to include as many complex processes to mimic the overall behavior of the natural system under specified conditions. Too little or too many processes could lead to inaccurate results or high computational cost (slow speed), respectively. The first step was to run Monte-Carlo simulations: thousands of program runs under different complexity, to single out just the required physics and anatomy to obtain a sweet spot between accuracy and speed. Second, we obtained data from a real plant *Acer glabrum* (a Maple species) and compared model results to the data to measure its accuracy. Third, by tweaking certain anatomical features in the model, it was possible to decipher their precise impact on whole-plant water use.

Based on real measurements of average conduit length in *Acer glabrum*, conduit diameter, conduit density, and porosity of conduit connections, the model was able to represent the effect of droughts on this species with groundbreaking precision. Moreover, as hypothesized, conduit topology was an important factor behind plant response to drought. For example, if longer and wider conduits possess less porous connections, the plant can better shield itself from increased drought intensity. This result guides future research toward an important but overlooked scale of plant anatomy: conduit topology.

The results of this study have future implications on the field of plant hydraulics: it is modular meaning that any new discovery can easily be added to the program. Like any computer model, this one has its limitations. For instance, some plants exhibit high variation in anatomical properties within a single branch or trunk cross-section, this requires incorporating not only the average length of conduits but also the level of variation of lengths. The current iteration of the model does not take into account this complexity.

As new needs arise, we expect the community of plant hydraulics scientists to use this model or variants of it to inform plant ecology through advances in plant anatomy. As hydrologists figure out new trends in rainfall, it is up to plant anatomists and ecologists to figure out how much water is returned to the atmosphere through the fascinating phenomenon of plant water use driven by photosynthesis.