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Modeling Water Uptake by Plant Roots

by Stacy Kish, CSREES

With changes in climate, farmers and ranchers must contend with diminishing water resources. One of the best ways to deal with this challenge is to maximize the efficiency of plant root systems, and researchers in North Dakota are taking steps to do just that. >>

With funding from USDA's Cooperative State Research, Education, and Extension Service (CSREES) National Research Initiative (NRI), Mario Biondini at North Dakota State University found a way to more accurately predict water uptake from plant roots by improving upon the West, Brown and Enquist (WBE) general model for scaling laws in biological networks.

Researchers use models extensively to test various agricultural research questions and natural resource management problems, such as soil quality, water and nutrient requirements and climate change.

The WBE model uses the geometry of network systems for resource exchange to predict the chemical reactions required for life sustaining functions in biological organisms. This model has been used in plant vascular systems to model the movement of water and nutrients in the xylem and phloem, the two types of transport tissue in the above ground parts of plants.

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Right: Root system for a fertilized 20 months old *Stipa comata* (needle and thread).

Credit: *Mario Biondini*

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The WBE model was designed for *closed systems*, where materials are exchanged only at the tip of the network. Therefore, the WBE is not the ideal model for predicting water uptake in *open systems*, such as the root systems of plants, where water can be exchanged throughout the entire network.

Maximizing water uptake in plant roots requires balancing two types of flow throughout the network. The first involves minimizing the resistance to flow inside the network, the longitudinal flow. The other involves maximizing water flow into the network, the transversal flow. Mathematically, the longitudinal flow is inversely proportional to the fourth power of the root radius, while the transversal flow is inversely related to the radius of the root.

Biondini modeled the optimal root radius for water uptake and transfer for any arbitrary volume and branching configuration. Model results were tested with data collected from 1,759 plants belonging to 77 herbaceous plant species. Other parameters considered in the model included soil type and drainage.

Results suggested that the root scaling configuration that maximizes water uptake is independent of water demand or soil/water distribution. In the model, Biondini used a simplified version of a root system that still captured the flow dynamics of the entire network.

Plant diversity and the sustainability of managed ecosystems are, in part, highly dependent on the volume of soil explored by root systems and the density and distribution of those root surfaces. Accurate modeling of root systems and their nutrient and water uptake, thus, is an essential tool for the planning and implementation of modern agro-ecosystem practices.

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Above: A Ph.D. student on the project setting up the trickle irrigation experiment.
Credit: Mario Biondini

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