LETTER

Calcium amendment may increase hydraulic efficiency and forest evapotranspiration

Green et al. (1) report 2 y of increased evapotranspiration (*ET*; calculated as the difference between total precipitation and total runoff) and decreased water yield following watershed-scale amendment of soil with wollastonite ($CaSiO_3$) at the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire. The watershed manipulation study was planned and executed within the context of concern over the relationship of forest health to soil cation mobilization, potential Ca depletion, and the threat to forest health and productivity.

That report demonstrates that water yield, an ecosystem service with high public interest, was affected by Ca biogeochemistry. The authors limit their discussion of the cause of increased *ET* following Ca amendment as being due either to increased numbers of stomata on the newly added foliage or to increased rates of water loss from stomata, and they suggest that the former is more likely. We suggest that increased Ca may enhance *ET* through improved hydraulic efficiency of the xylem conduits.

Regardless of source, biologically available Ca occurs as the divalent cation. Following entry into the root apoplast, Ca^{2+} follows the concentration gradient by ion displacement through the Donnan free space of the cell wall system (2). Xylem sap in the *Picea rubens* (red spruce) model system decreased in [Ca^{2+}] along the stem flowpath and into the branches (3). This decrease in free ion content reflected both the utilization of Ca^{2+} to cross-link cell wall polysaccharides and the input of small yet essential quantities of Ca^{2+} into the symplast, including the cell membrane system. Although low in concentration, symplastic Ca^{2+} facilitates water flow from the apoplast into the symplast through the stimulation of aquaporin formation (2). Of greater importance with respect to *ET*, apoplastic Ca^{2+} produces an "ionic effect" that alters the dynamic apoplastic matrix and increases the hydraulic flux in the conducting elements of the xylem (4). The mechanism responsible for the increased flow in the apoplast likely involves the pectic hydrogels that cross-link pit membranes of the xylem-conducting elements, although the precise mode of action remains to be identified (5).

Whatever the mechanism of increased *ET*, the more intriguing question may be whether increased *ET* affects water use efficiency (WUE, the ratio of carbon fixed in photosynthesis to water lost through transpiration). This may represent another physiological implication of Ca biogeochemistry through an effect on the efficiency of carbon capture. Carbon capture and the potential for carbon sequestration, as well as water yield, are ecosystem services likely affected by Ca biogeochemistry in multiple ways.

As Green et al. (1) point out, macroscale approaches to describe atmospheric and ecosystem processes may be insufficient to assess local ecosystems. Similarly, we suggest that a widespread yet microscale process within living trees can be a fundamental driver of landscape processes.

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