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Variable coupling between sap-flow and transpiration in pine trees under drought conditions

Yakir Preisler (1,2), Fyodor Tatarinov (1), Shani Rohatyn (1,2), Eyal Rotenberg (1), Jose M. Grunzweig (2), and Dan Yakir (1)

(1) Weizmann institute of science, Earth and planetary science, Rechovot, Israel, (2) Faculty of Agriculture, Food and Environment and The Advanced School for Environmental Science. The Hebrew University of Jerusalem, Rehovot, Israel.

Changes in diurnal patterns in water transport and physiological activities in response to changes in environmental conditions are important adjustments of trees to drought. The rate of sap flow (SF) in trees is expected to be in agreement with the rate of tree-scale transpiration (T) and provides a powerful measure of water transport in the soil-plant-atmosphere system. The aim of this five-years study was to investigate the temporal links between SF and T in *Pinus halepensis* exposed to extreme seasonal drought in the Yatir forest in Israel. We continuously measured SF (20 trees), the daily variations in stem diameter (ΔDBH, determined with high precision dendrometers; 8 trees), and ecosystem evapotranspiration (ET; eddy covariance), which were complemented with short-term campaigns of leaf-scale measurements of H_2O and CO_2 gas exchange, water potentials, and hydraulic conductivity. During the rainy season, tree SF was well synchronized with ecosystem ET, reaching maximum rates during midday in all trees. However, during the dry season, the daily SF trends greatly varied among trees, allowing a classification of trees into three classes: 1) Trees that remain with SF maximum at midday, 2) trees that advanced their SF peak to early morning, and 3) trees that delayed their SF peak to late afternoon hours. This classification remained valid for the entire study period (2010-2015), and strongly correlated with tree height and DBH, and to a lower degree with crown size and competition index. In the dry season, class 3 trees (large) tended to delay the timing of SF maximum to the afternoon, and to advance their maximum diurnal DBH to early morning, while class 2 trees (smaller) advanced their SF maximum to early morning and had maximum daily DBH during midday and afternoon. Leaf-scale transpiration (T), measurements showed a typical morning peak in all trees, irrespective of classification, and a secondary peak in the afternoon in large trees only. Water potential and hydraulic conductivity in larger trees recovered faster from midday depression than in smaller ones. We concluded that the observed changes in the patterns of water flow into and out of the trees reflected differences in the utilization of external and internal 'water storage'. Large trees appear to rely on sufficient internal water storage that filled up in the morning (max DBH) and supported transpiration both in the morning and the afternoon, while SF increased throughout the day to compensate for the depletion in water storage (SF maximum in the afternoon). In contrast, small trees with insufficient internal water storage must rely on soil water availability and maximize SF in the morning to support concurrent tree transpiration, achieving some internal storage only in the afternoon, when T declines and maximum daily DBH is observed. The results indicated also that trees with insufficient internal storage, as can be detected by the simultaneous SF and DBH patterns, are likely to be more vulnerable to drought-related mortality since soil water availability may not be sufficient to support transpiration and stomata opening.