Geophysical Research Abstracts
Vol. 17, EGU2015-3526-1, 2015
EGU General Assembly 2015

Large variations in diurnal and seasonal patterns of sap flux among Aleppo pine trees in semi-arid forest reflect tree-scale hydraulic adjustments

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Adjustments and adaptations of trees to drought vary across different biomes, species and habitats, with important implications for tree mortality and forest dieback associated with global climate change. The aim of this study was to investigate possible links between the patterns of variations in water flux dynamics and drought resistance in Aleppo pine (Pinus halepensis) trees in a semi-arid stand (Yatir forest, Israel). We measured sap flow (SF) and variations in stem diameter, complemented with short-term campaigns of leaf-scale measurements of water vapour and CO_2 gas exchange, branch water potential and hydraulic conductivity, as well as eddy flux measurements of evapotranspiration (ET) from a permanent flux tower at the site.

SF rates were well synchronized with ET, reaching maximum rates during midday in all trees during the rainy season (Dec-Apr). However, during the dry season (May-Nov), the daily trend in the rates of SF greatly varied among trees, allowing classification into three tree classes: 1) trees with SF maximum rate constantly occurring in mid-day (12:00-13:00); 2)trees showing a shift to an early morning SF peak (04:00-06:00); and 3) trees shifting their daily SF peak to the evening (16:00-18:00). This classification did not change during the four years study period, between 2010 and 2014.

Checking for correlation of tree parameters as DBH, tree height, crown size, and competition indices with rates of SF, indicated that timing of maximum SF in summer was mainly related to tree size (DBH), when large trees tended to have a later SF maximum. Dendrometer measurements indicated that large trees (high DBH) had maximum daily diameter in the morning during summer and winter, while small trees typically had maximum daily diameter during midday and afternoon in winter and summer, respectively.

Leaf-scale transpiration (T) measurements showed typical morning peak in all trees, and another peak in the afternoon in large trees only. Different diurnal curves observed during the dry season, indicated that water potential and hydraulic conductivity values in larger trees restored from midday depression earlier than in smaller ones.

The results demonstrate large heterogeneity in the behaviour related to tree water relations among trees of the same species and in the same stand. The combination of diurnal leaf-scale measurements, SF and changes in DBH demonstrated the different strategies of individual trees of different sizes. Large trees with sufficient internal water storage can more freely manipulate their water storage capacity, with reduced dependence on environmental conditions (e.g., morning and afternoon peaks of T).

On the other hand, during the dry summer small trees with insufficient internal water storage are strongly restricted by low soil water availability and extreme environmental conditions, which is expressed in only one peak of T, midday to afternoon shift of diurnal DBH maximum, and shift in SF to predawn when soil water potential is highest. Refilling of internal water storage seems to be in the afternoon/evening since T becomes smaller than SF and DBH increases. Reliance on external water availability in small trees might be insufficient during long drought episodes when soil water content decreases below threshold required for extraction by the trees, leading to increased tree mortality in small DBH trees.