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# Separating the effects of soil and atmospheric water deficits on water use efficiency in a semi-arid pine forest

**K. Maseyk**, E. Rotenberg, D. Yakir
Weizmann Institute of Science, Rehovot, Israel

Water and carbon exchange between the land and atmosphere are intimately linked through the vegetation interface. The atmosphere-to-vegetation flux of carbon during the process of photosynthesis is coupled to the soil-to-atmosphere flux of water though plant transpiration. Therefore there is interplay between the direct affect of climatic drivers on the processes of photosynthesis and transpiration and the ecological response of the plants under given environmental conditions. Therefore the relationship between the rates of water loss and carbon uptake (water use efficiency, WUE), is key parameter for understanding the vegetation mediated water fluxes of a system. Understanding the controls over WUE is particularly important in water-limited environments, where vegetation is highly sensitive to environmental water potentials.

The environmental drivers of transpiration include both soil water content (SWC) and atmospheric water vapour pressure deficit $(D)$, which are manifested in a manner dependent on the properties of the plant soil-to-leaf hydrological pathway. In summer-dry arid regions, the seasonal decrease in SWC is often correlated with an increase in $D$, so separating their relative effects on canopy water use efficiency can be difficult. We have taken advantage of the location of a pine forest growing in semi-arid conditions at the interface between Mediterranean and desert climate zones in Israel to explore the relative influence of atmospheric and soil water deficits on WUE. Measurements of WUE have been derived from continuous ecosystem carbon and water flux measurements at a micrometeorological flux-tower in the forest over a period of 5 years. The highly seasonal nature of the environment and variable relative influence of the two adjacent climate zones result in the ecosystem experiencing a large range of $D$ over the range of SWC. In particular, synoptic-scale climatic events occur periodically that involve air masses from the southern desert area passing over the region, resulting in a dramatic increase in $D$ (from $<$1 kPa to $>$4 kPa) over a period of $\sim$3 days. These unique natural ecosystem-scale experiments occur a few times a year, usually in the transition seasons and at a range of different SWC. Therefore the effect of $D$ on carbon and water fluxes can be analyzed independent of confounding seasonal plant effects (e.g. adjustments in photosynthetic capacity or hydraulic conductance). In particular, it has been possible to determine the soil water content dependence of the atmospheric deficit effect on WUE.

There is a linear decrease in carbon fluxes (gross photosynthesis, GP) with the short-term increase in $D$, consistent with stomatal responses observed from leaf scale measurements. Both the slope and the intercept of the GP-$D$ relationship decrease with soil water content, leading to a linear relationship between dGP/d$D$ and SWC when soil water is limiting. Water fluxes were more complex and were dependent on soil water content and tree soil-to-leaf hydraulic conductance, but generally remained relatively constant as $D$ increased above $\sim$2 kPa. Consequently, WUE decreased with increasing $D$, but the nature of this relationship was influenced by soil water content. Overall, in absolute terms, $D$ is shown to have a stronger influence on WUE than SWC, resulting in WUE being lowest in midsummer, when it is often assumed WUE is highest.