Convergence of the effect of root hydraulic functioning and root hydraulic redistribution on ecosystem water and carbon balance across divergent forest ecosystems

Details

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Abstract

INVITED ABSTRACT: Deep root water uptake and hydraulic redistribution (HR) play a major role in forest ecosystems during drought, but little is known about the impact of climate change on root-zone processes influencing HR and its consequences on water and carbon fluxes. Using data from two old growth sites in the western USA, two mature sites in the eastern USA, one site in southern Brazil, and simulations with the process-based model MuSICA, our objectives were to show that HR can 1) mitigate the effects of soil drying on root functioning, and 2) have important implications for carbon uptake and net ecosystem exchange (NEE). In a dry, old-growth ponderosa pine (USA) and a eucalyptus stand (Brazil) both characterized by deep sandy soils, HR limited the decline in root hydraulic conductivity and increased dry season tree transpiration (T) by up to 30%, which impacted NEE through major increases in gross primary productivity (GPP). The presence of deep-rooted trees did not necessarily imply high rates of HR unless soil texture allowed large water potential gradients to occur, as was the case in the wet old-growth Douglas-fir/mixed conifer stand. At the Duke mixed hardwood forest characterized by a shallow clay-loam soil, modeled HR was low but not negligible, representing annually up to 10% of T, and maintaining root conductance high. At this site, in the absence of HR, it was predicted that annual GPP would have been diminished by 7-19%. At the coastal loblolly pine plantation, characterized by deep organic soil, HR limited the decline in shallow root conductivity by more than 50% and increased dry season T by up to 40%, which increased net carbon gain by the ecosystem by about 400 gC m-2 yr-1, demonstrating the significance of HR in maintaining the stomatal conductance and assimilation capacity of the whole ecosystem. Under future climate conditions (elevated atmospheric [CO2] and temperature), HR is predicted to be reduced by up to 50%; reducing the resilience of trees to droughts. Under future conditions, T is predicted to stay the same at the Duke mixed hardwood forest, but to decline slightly at the coastal loblolly pine plantation and slightly increase at the old-growth ponderosa pine stand and the eucalyptus plantation. As a consequence, water use efficiency in all sites was predicted to improve dramatically under future climate conditions. Our simulations also showed that the negative effect of drier nights on HR would be greater under future climate conditions. Assuming no increase in stomatal control with increasing drier nights, increased vapor pressure deficit at night under future conditions was sufficient to drive significant nighttime T at all sites , which reduced HR, because the plant and the atmosphere became a sink for hydraulically redistributed water . We concluded that the predicted reductions in HR under future climate conditions are expected to play an important regulatory role in land-atmosphere interactions by affecting whole ecosystem carbon and water balance. We suggest that root distribution should be treated dynamically in response to climate change and that HR and its interactions with rooting depth and soil texture should be implemented in soil-vegetation-atmosphere transfer models.

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