PINEMAP

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The Canopy Underground: Convergence of the Effect of Root Hydraulic Functioning and Root Hydraulic Redistribution on Ecosystem Carbon Balance Across Divergent Loblolly Pine Forests

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Executive Summary

Deep root water uptake and hydraulic redistribution (HR) have been shown to play a major role in forest ecosystems during drought, but little is known about the impact of climate change, fertilization, and soil characteristics on HR and its consequences on water and carbon fluxes. Using data from three mid-rotation loblolly pine plantations and simulations with the process-based model MuSICA, this study indicated that HR can mitigate the effects of soil drying and had important implications for carbon uptake potential and net ecosystem exchange (NEE), especially when N fertilization is considered.

Background

Under future climate scenarios predicted for parts of the loblolly pine range, tree stress resulting from drought is expected to become more pronounced. Root water uptake is governed by the rate of tree transpiration, the resistance to water flow through xylem, and the spatial distribution of absorbing roots in soil with heterogeneous areas of moisture availability. When trees are rooted through soil horizons with differing amounts of moisture, passive movement of water from moist soil horizons to drier soil horizons may occur via roots; this process is called hydraulic redistribution (HR). Deep root water uptake and HR play a major role in forest ecosystems during drought, such as prolonging survival of fine roots in dry soil. Even so, little is known about the impact of climate change, nitrogen fertilization, and soil characteristics on HR and the resulting impacts on transpiration rates, carbon partitioning, and whole ecosystem productivity.

Methods

We used data from three loblolly pine plantations with contrasting soil types in North Carolina (a piedmont site with shallow clay-loam soil, a coastal site with deep organic soil, and a site with sandy soil) and simulations with the process-based model MuSICA to:

1. Estimate how important the observed differences in water use between sites were for the maintenance of water uptake under reduced precipitation and increased temperature and CO_2 equivalent (eCO_2);
2. Test the hypothesis that under future higher evaporative demand, night transpiration will be enhanced and HR reduced, thus impacting tree water use (*T*), gross primary productivity (GPP), and water use efficiency; and
3. Stress the impact of climate change, eCO_2, and N fertilization on *T*, HR, GPP, and water use efficiency.

Results

This study found that HR can mitigate the effects of soil drying and has important implications for net ecosystem exchange of carbon and carbon uptake potential under current and future climate conditions, especially when nitrogen fertilization is considered. Specifically, at the coastal loblolly pine site characterized by deep organic soil, HR increased dry season tree transpiration by up to 40%, which in turn affected net carbon fluxes through major changes in gross carbon uptake or total photosynthesis. At the Piedmont site characterized by a shallow clay-loam soil, HR was low but not negligible, representing up to 10% of growing season water use. Deep-rooted trees did not necessarily translate into a large volume of HR unless soil texture allowed significant differences in water availability among horizons to develop, as was the case at the sandy site.

Implications

Under future climate conditions, characterized by an increase in air temperature, vapor pressure deficit (air dryness or evaporative power), and atmospheric CO_2, it is predicted that HR will be reduced by up to 25%, limiting the resilience of trees to drought. Our results highlight the interactive effects of nutrients and elevated CO_2 and show that the effect of nitrogen fertilization would be greater under future climate conditions. Our simulations also show that there would be a greater negative effect of drier nights on HR under future climate conditions. We concluded that the predicted reductions in HR under drier and hotter climatic conditions are expected to play an important regulatory role in land-atmosphere interactions by affecting whole ecosystem carbon and water balance. The same analysis can be used to demonstrate that models operating without including deep roots and HR will project overly sensitive responses of vegetation to drought, which may explain why many models fail to capture observed vegetation responses under droughts. We therefore 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. Incorporating the effects of deep root function and HR in models will empower the refinement of models that can capture the effects of climate change in the future and will improve the application of new forest management approaches aimed at increasing forest resilience and sustainability under variable climates.

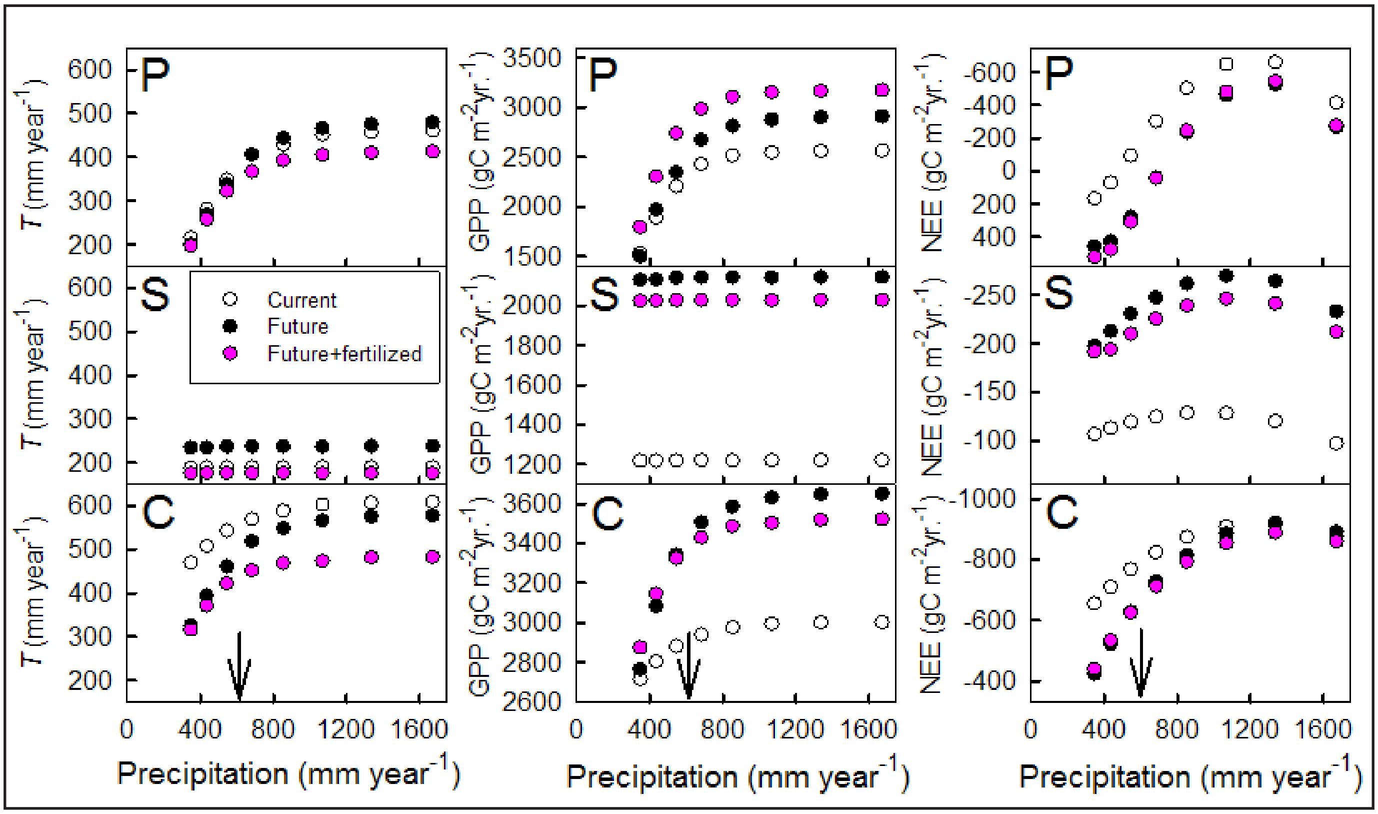

Figure 1. Effect of precipitation on modeled (MuSICA) tree transpiration (*T*), gross primary productivity (GPP), and net ecosystem exchange (NEE) at the three North Carolina sites (C = coastal site, S = s-andy site, and P = piedmont site). Simulations are given under current conditions as well as under future conditions (temperature = +3°C; CO_2 concentration = 600 μmol mol–1), and under future conditions plus N-fertilization. The arrows represent the minimum precipitation ever recorded for these sites (i.e., 590-640 mm). Note that because of the reduced hydraulic redistribution under future conditions at the coastal site, the reduction in *T*, GPP, and NEE was predicted to be more sensitive to reduced precipitation under future conditions. For example, from the figure we can see that a reduction in annual rainfall from 900 mm to 450 mm would reduce *T* by 19% under current conditions and by 36% under future conditions. At the other two sites, since hydraulic redistribution represented less than 11% of *T*, the reduction in hydraulic redistribution had a minor effect on the response of *T* and GPP to precipitation.

For additional information on this research, contact J.C. Domec (jdomec@ncsu.edu) or access the complete manuscript:
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