7. Using the Tier III Experiments to Investigate the Effects of Drought and Fertilization on Forest Water Use and Stomatal Conductance

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The effects of fertilization and drought on the leaf area of forest canopies and the amount of water used by those canopies are important factors in determining the productivity of forests. Such information is critical in forming management recommendations that increase forest resilience to climate variability and disturbance.

The leaf area and transpiration of forest canopies are primary factors determining stand growth in PINEMAP modeling efforts. Thus, this research forms an important interdisciplinary link between data collected in the field and computer models used to forecast future scenarios.

When trees open their stomata (microscopic leaf pores) to allow carbon dioxide (CO_2) into the leaf for photosynthesis, water is lost through the stomata (transpiration, E_C) as a consequence. The degree of stomatal opening, also called stomatal conductance (G_S), is actively regulated by the tree throughout the day in response to both photosynthetic demand for CO_2 and the stress induced by water loss. At the stand level, the total amount of photosynthesis and transpiration is heavily influenced by the amount of leaves in the tree canopy, quantified as Leaf Area Index (LAI), the area of leaves per unit ground area. Because the stomata regulate both water loss and carbon gain, our understanding of forest transpiration, leaf area index, and stomatal conductance under different scenarios is linked to our understanding of forest growth, productivity, and carbon uptake potential. In the previous annual report, we outlined how researchers are using a network of hundreds of sensors that measure water movement in the trunks of trees, or *sap flux density,* to quantify stand transpiration at the Tier III throughfall reduction x fertilization experiments (see Chapter 1, page 6) where we are investigating the effects of drought and fertilization on loblolly pine stands. In that report, we described the sampling of sap flux density and important environmental variables, including centralized data collection and automated programs for quality control and data processing, and we presented early results from the Tier III experiment in Buckingham County, Virginia. For the 2013 growing season (the first full year after the imposition of treatments in the first half of 2012), we present results from this site; a site in Taliaferro County, Georgia; and a site in Taylor County, Florida.

Methods

At each site, we measured sap flux density in trees in four different treatments: control (C), ~30% throughfall reduction (R), fertilization (F), and the combination of throughfall reduction and fertilization (FR). We use a hierarchical Bayesian state-space approach (Ward et al. 2013) to infer mean stomatal conductance from sap flux data at half-hour increments for each treatment at each site. Use of a common analytical platform facilitates integration of analyses across sites and ensures the comparability of results.

Tier III Treatment	Measurements
C: Control	**LAI:** Leaf area index, area of leaves per unit ground area
R: ~30% throughfall (rainfall) reduction	**G_S:** Stomatal conductance or degree of stomatal opening per unit leaf area
F: Fertilization	**E_C:** Transpiration or amount of water loss per unit ground area
FR: ~30% throughfall (rainfall) reduction plus fertilization	

Results and Discussion

Treatment effects on stand leaf area index would be expected to translate to proportional changes in transpiration per unit ground area (E_C) unless changes in the regulation of stomatal conductance per unit leaf area (G_S) are observed. In general, we may expect the throughfall reduction treatment to have low LAI, due to decreased water availability, and the fertilization treatment to have high LAI, due to increased nutrient availability. We did not see a consistent pattern of LAI across sites during the spring of 2013, when LAI is at its annual minimum (Figure 7.1). By the beginning of autumn 2013,

PINEMAP field researcher Joshua Cucinella measures leaf area index (LAI) at the PINEMAP Tier III throughfall reduction x fertilization site in Taylor County, Florida. Photo by Jessica Ireland.

Increases in transpiration may be less than proportional to increases in LAI due to fertilization in a future climate with reduced rainfall because stomata will close in response to increased water stress.

when LAI is at its annual maximum, we began to see the expected pattern of LAI between treatments at the Georgia and Florida sites but not at the Virginia site. Loblolly pine needles have an average longevity of 18 to 24 months, so stand LAI may take multiple years to respond to treatments (McCarthy et al. 2007) and overcome any initial differences between plots. Results will be of particular interest if expected patterns in LAI strengthen as growth responds to treatments at each site.

Following the pattern of LAI, we saw that E_C is higher in the fertilization treatment relative to the control for most of the growing season at the Georgia and Florida sites (Figure 7.2, left panels), where LAI exhibited an increase due to this treatment. At the Georgia site, we saw a reduction in E_C in the throughfall reduction treatment, where both minimum and maximum LAI were lower; at the Florida site, the throughfall reduction treatment had higher E_C and LAI in the early growing season but not the later growing season. However, when we examined G_S, we saw that not all differences in water use were explained by LAI alone. Of particular note was that the combined throughfall reduction and fertilization treatment had lower G_S than the control in most of the growing season at all three sites (Figure 7.2, right panels). This suggests that the combined effects of throughfall reduction, which reduces soil water availability, and fertilization, which tends to shift carbon allocation away from roots to aboveground components such as leaves, may produce more water stress and decreased G_S in trees than either treatment in isolation.

This suggests that increases in transpiration may be less than proportional to increases in LAI due to fertilization in a future climate with reduced rainfall because stomata will close in response to increased water stress. However, increased atmospheric demand for water vapor is likely to accompany reduced rainfall and could increase transpiration despite decreases in G_S. Such results highlight the importance of integrating field research with process-based models, allowing for better interpretation of empirical observations in the context of future climate and management scenarios.

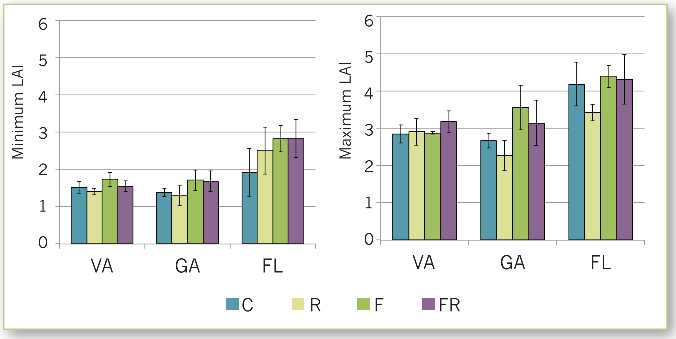

Figure 7.1. Mean leaf area index (LAI, m^2 leaf m^{-2} ground) for control (C), throughfall reduction (R), fertilization (F), and combined (FR) treatments for the Tier III sites in Virginia, Georgia, and Florida. Minimum LAI (left) represents measurements taken March through May 2013 and maximum LAI (right) represents measurements taken August through October 2013. Bars represent standard deviation (n = 4 per site).

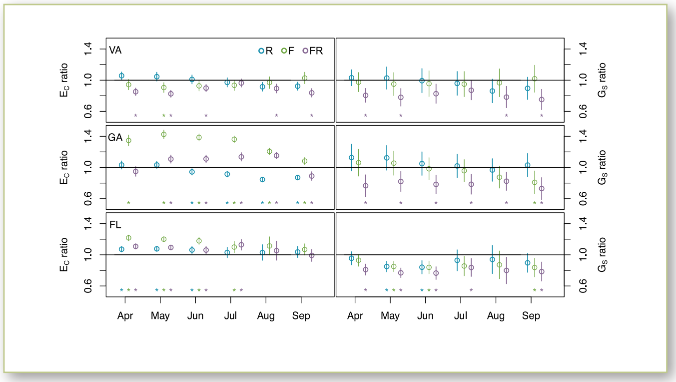

Figure 7.2. Monthly mean estimates of canopy transpiration (E_C) and daytime stomatal conductance (G_S) for throughfall reduction (R), fertilization (F), and combined (FR) treatments expressed as a ratio of the control treatment at Tier III sites in Virginia, Georgia, and Florida. Ratios falling on the 1.0 line would have the same value as the control treatment. Error bars represent 95% confidence using a normal parametric bootstrap of monthly mean values.