Fertilization intensifies drought stress: Water use and stomatal conductance of *Pinus taeda* in a midrotation fertilization and throughfall reduction experiment

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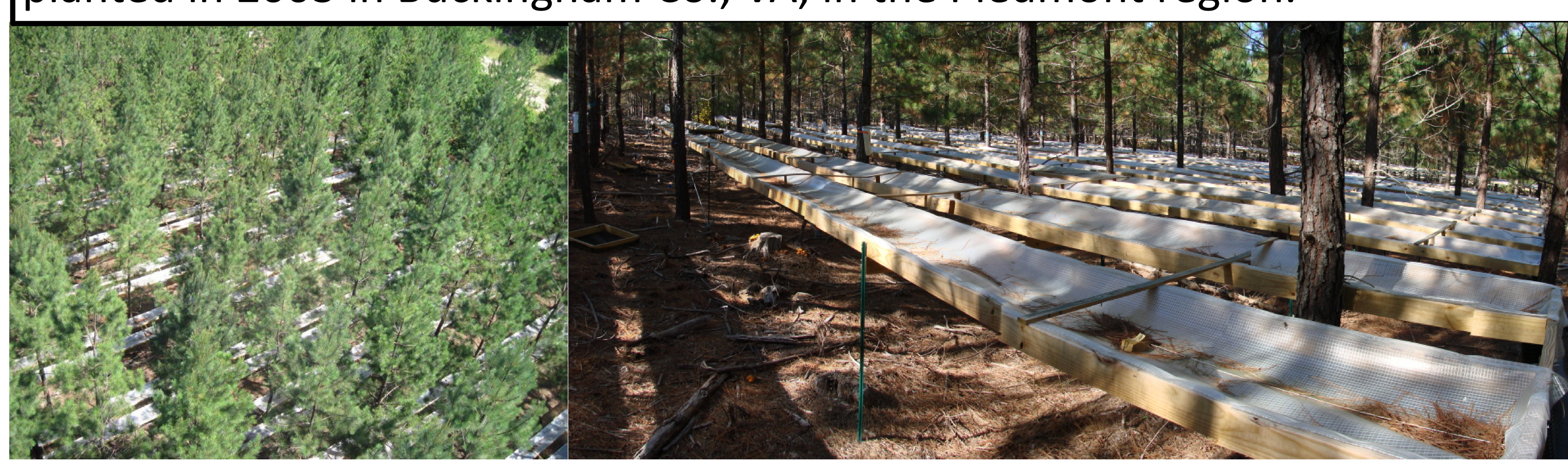
Project Goals

The Pine Integrated Network: Education, Mitigation, and Adaptation Project (PINEMAP) focuses on improving models of forest carbon and water cycling with both existing and novel data from a variety of studies. The goal of PINEMAP is to integrate current knowledge of the management of 20 million acres of loblolly pine (*Pinus taeda*) stands in the southeastern US to achieve 3 main goals: (1) to increase carbon sequestration, (2) to increase efficiency of nitrogen and other fertilizer inputs, and (3) to adapt forest management approaches to increase forest resilience and sustainability under variable climates. This project seeks to combine remote sensing data with that from the several thousand existing inventory plots and 4 newly established sites in VA, GA, FL and OK with control (C), one-time fertilization (F), 30% throughfall displacement (D) and fertilization x throughfall displacement (FD) treatments in 4 blocks. This study began in April 2012 in a stand planted in 2003 in Buckingham Co., VA, in the Piedmont region.



Pictures showing rainfall excluders courtesy of M.A. Laviner and Virginia Department of Forestry

Site Measurements

Half-Hourly Data

- Sap Flux Density (J_S)
- Light (PAR) and Air Temperature
- Air Vapor Pressure Deficit (VPD)
- Volumetric Soil Moisture (VSM)
- Precipitation and Throughfall

Annual/Seasonal Data

- Height, DBH Surveys
- Carbon, Nitrogen Pools
- Crown Length, Width
- Leaf Area Index (LAI)
- Canopy Light Transmission

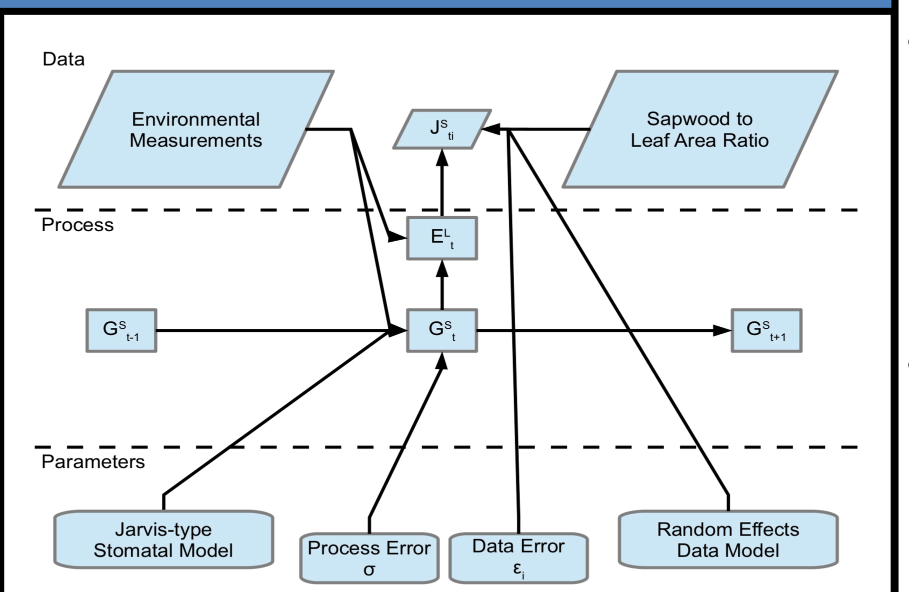
Bayesian State-Space Approach to Stomatal Conductance

Features

- Consistent approach across sites to analyzing sap flux data
- Clear assumptions about missing data, scaling to stomatal conductance (G_S)
- Uncertainty associated with G_S and transpiration per unit LAI (E_C)
- Responses to environmental drivers

Inputs

- Clean sap flux estimates
- PAR, VPD, VWC
- Plot sapwood and leaf area
- Parameter prior distributions



Outputs

- Posterior distribution of transpiration and stomatal conductance
- Posterior distribution of stomatal response parameters and covariance

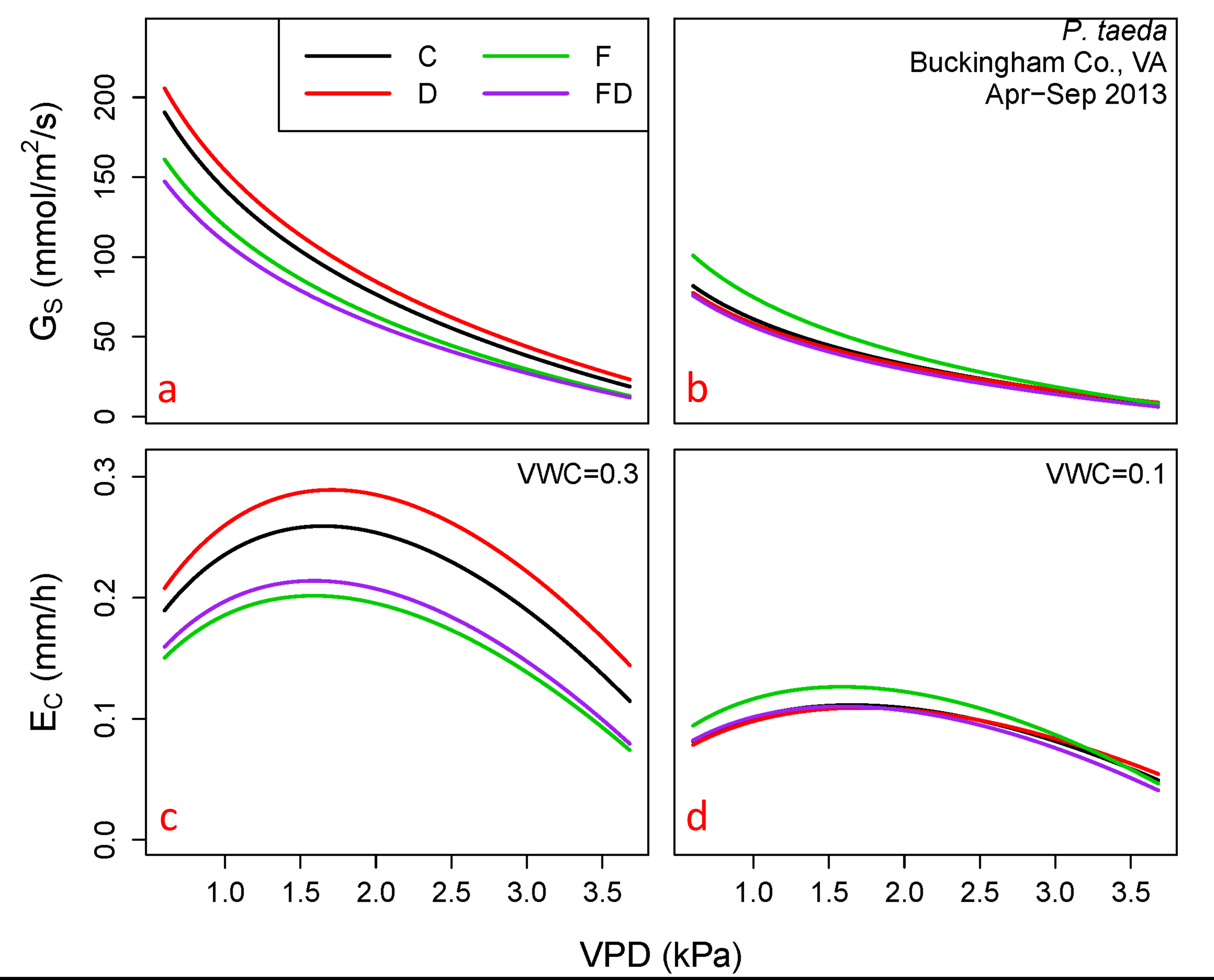


Fig. 2: Mean responses of canopy transpiration per unit ground area (E_C) and canopy-averaged stomatal conductance per unit leaf area (G_S) to vapor pressure deficit (VPD) at two different volumetric water contents of the soil (VWC), under saturating light conditions, as inferred from posterior process parameters for the 2013 growing season. E_C values assume mean leaf area index for the model period.

Conclusions

- Overall, our results indicate that despite unusually high rainfall in the study period and a lack of leaf area index (LAI) response, both E_C and G_S decreased in response to fertilization and throughfall reduction.
- Fertilization increased stem volume increment 20% in 2013. Treatment differences were greatest in the growing season of 2013, when E_C was on average 19, 13 and 29% lower in the throughfall reduction (D), fertilization (F) and combined treatment (FD) than the control (C), respectively.
- The responses of G_S to volumetric soil water content (VWC) indicate that lower E_C in F resulted from a decrease in G_S at high VWC, while those in D were due to G_S responses to low VWC from throughfall reduction. Decreases observed in FD resulted from a combination of these two factors.
- These results are consistent with fertilization-induced decreases in allocation to fine root biomass or hydraulic conductivity, which then impose water limitation comparable to that caused by the throughfall exclusion.
- If such a response were to persist beyond the initial years of fertilization and past canopy closure, the physiological drought experienced by fertilized forests would be greater than by nutrient-limited forests under same hydrologic conditions, potentially increasing their vulnerability to hydraulic failure.

Fig. 1: Estimated monthly daytime canopy-averaged stomatal conductance (a, G_S, mmol m^{-2} leaf area s^{-1}) and canopy transpiration (c, E_C, mm per unit ground area) in each treatment (c) and the ratio of the E_C in each treatment to the control value (b,d), where a 95% credible interval of the control is indicated by the dotted line and by error bars for treatment values. Small symbols at the top and bottom of panels b and d represent treatments where monthly value was different from the control with 95% confidence using a normal parametric bootstrap of model posterior values. Monthly values are staggered for clarity.

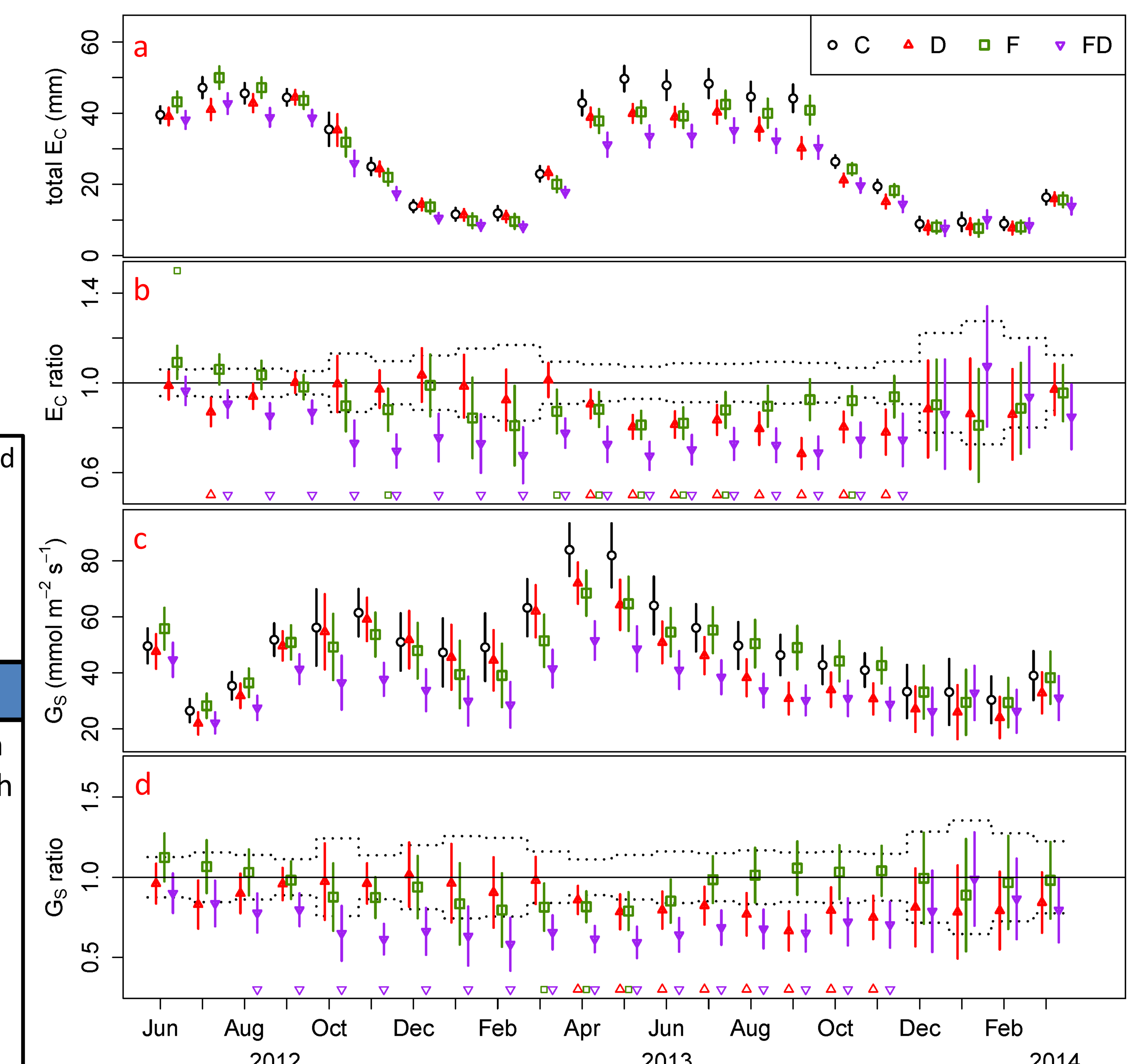
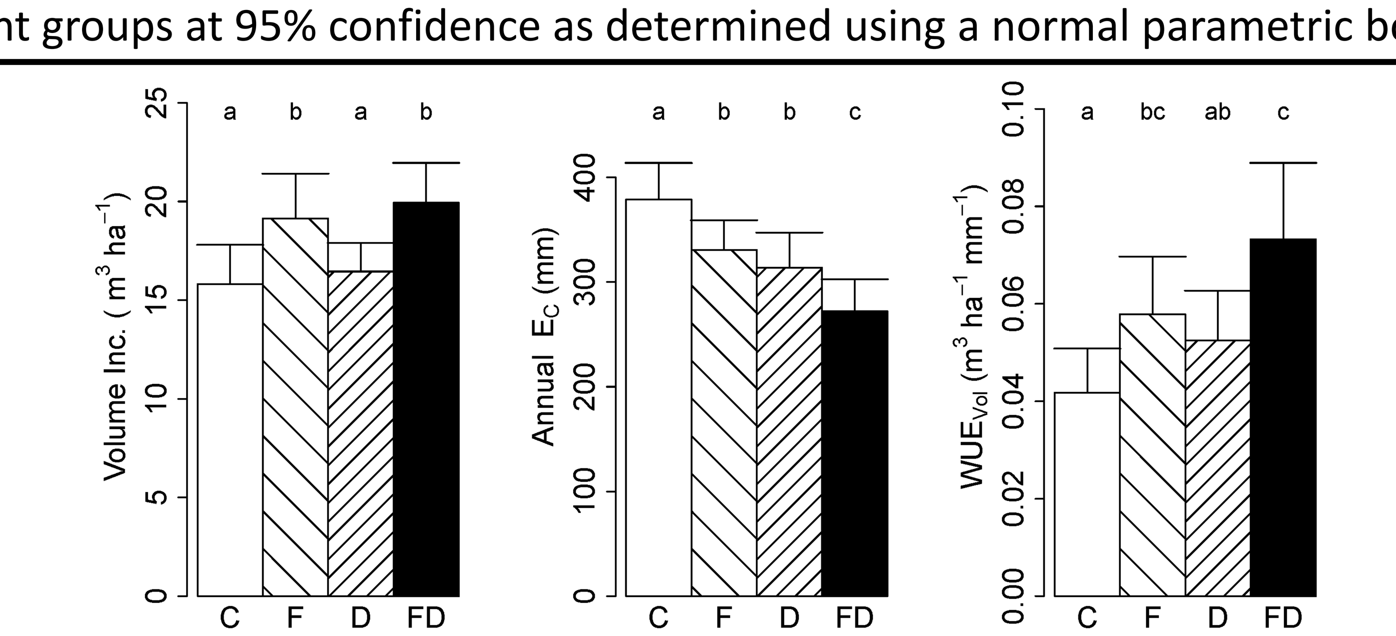


Fig. 3: Stem volume increment, annual transpiration per unit ground area (E_C) and water use efficiency of stem volume production (WUE_{Vol}) for each treatment in 2013. Error bars represent standard error of treatment means for stem volume increment (n=4), standard deviation for posterior distributions of E_C in each treatment, and the fractional sum of these error estimates for WUE_{Vol}. Lowercase letters above each bar represents different groups at 95% confidence as determined using a normal parametric bootstrap.



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