Impacts of Genetic Variation and Silvicultural Treatments on Loblolly Pine Water Use

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Executive Summary

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Date

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**1 Introduction**

Water moves passively from soil into the atmosphere through the root, xylem, and shoots of trees, carrying necessary nutrients and supports photosynthesis (Sinha, 2004). Transpiration is defined as the amount of water used in this process (Hanrahan, 2011). Plant transpiration is an integrate part of local and global carbon and hydrological cycle (Jasechko et al., 2013).

Transpiration responds to both biotic and abiotic factors including individual tree crown architecture, planting density, water content in the air, and soil moisture. Transpiration changes with tree characteristics as the conductance of water flow varies with each tree’s morphology and physiology (Kimball, 2007). Crown architecture, or ideotype, is restricted to consistent morphological expressions including crown size, density, branching patterns, angle of leaves relative to each other, etc. (Dickmann, 1985; Martin, Johnsen, & White, 2001). Although it is innate with a tree’s genetic entry, the traits can be influenced by environmental factors (Carbaugh, 2015). Crown ideotype largely defines leaf area, an important measure of plant growth and productivity as it determines light interception and transpiration (Vose & Allen, 1988; Wright et al., 2004).

Spacing is a common silvicultural practice to meet various management objectives. Spacing regimes affect transpiration by manipulating the interactions between trees. High planting density promotes competition and reduces individual tree sizes (Carlson et al., 2009; Harms, Whitesell, & DeBell, 2000), thus encourages narrow crown development—vice versa for low planting density. Past study has proven that low planting density of P. taeda yields greater diameter branches and stem, foliage and branch biomass, leaf area and canopy density, longer-lived crown, lower height to live crown and lower foliage to branch mass ratio comparing to high planting density (Albaugh et al., 2019; Akers et al., 2012).

Because water movement follows a high to low water potential gradient, moving from wet to dryer places, the low water potential in the ambient air becomes the primary driving force deciding how much water is pulled out through leaf stomata (Freeman, 2014). This water potential, or how “wet/dry” the air is, can be expressed as vapor pressure deficit (VPD, the measure of how much water is in the air versus the maximum amount of water vapor that can exist in that air or fully saturated air) (Lawrence, 2005).

Soil water availability is another critical consideration especially when we are facing the challenge of climate change, as drought is the primary factor contributing to reduced productivity and increased mortality (Allen et al., 2010). Zhao and Running (2009) estimated a drought-induced reduction of 0.55 petagram carbon in global net primary productivity from 2000 to 2009. Plants can cope with restricted water supply by closing their stomata to stop transpiring, at the same time pausing photosynthesis (Agurla et al., 2018). Permanent cavitation of water-transporting xylems can occur when extreme water potential difference “breaks” the water continuum, consequently, reduces a tree’s ability to conduct water, to grow and to survive (Zhang et al., 2016). Thus, transpiration can be affected by stomata closure drastically under different water availabilities, expressed as soil moisture measurements. The amount of water available to plants can be expressed as soil moisture percentage.

Transpiration can be either estimated or directly measured. Gauged watershed method simply subtracts runoff from precipitation to generate transpiration (Hasenmueller & Criss, 2013,); energy balance methods such as the Penman-Monteith Equation considers transpiration as component of an integrated mass-transfer system and estimates transpiration from stomatal conductance (Monteith & Unsworth, 1990); the Eddy covariance and flux gradient method calculates flux by computing the covariance between fluctuations in vertical wind velocity and fluctuations of transferred properties such as heat and moisture (Lee & Law, 2004); there are also various hydrological models for estimating transpiration (Vose & Swank, 1992). On the other hand, direct measurements of individual tree sap flow provide the basis for above methods and generates most reliable results (Vose et al., 2003). Granier (1985) proposed sap flux density as a function thermal conductivity. A thermal sensor with two probes, one electrically heated at upper position and one at ambient temperature at lower position, is inserted into the sapwood of a tree trunk where water transportation occurs (Liu, Urban & Zhao, 2004). The heat dissipated by the upper probe affects the temperature of the lower probe. The temperature differences between the two probes can therefore be transformed into sap flux density, or how quickly water is passing through xylem using the empirical function Fd = 119 \*k^1.231, where Fd is sap flux density (g H2O/m-2/s-1) and k is the flow index calculated from the temperature differential between heated and non-heated probes. From the point measurements, we can scale it up to tree-level and stand-level transpiration using sapwood area.

**1.1 Goals & Objectives**

In this MP, we tested two biotic factors that theoretically affect transpiration: crown architecture and planting density. Four genetic entries were chosen to represent different crown architectures that represent narrow and broad crown ideotypes. We were interested in how water costs might differ for each ideotype and planting density, along with their interactions. We also wanted to test the variation in responses to environmental factors. We evaluated whether there is a difference in how each treatment group respond to VPD; because the stomata closure response can change transpiration drastically, we were also interested in how P. taeda transpiration responds to VPD with seasonal changes in soil moisture.

This Master’s Project (MP) exists as part of a larger project collaborated between United States Forest Service (USFS), North Carolina State University, Virginia Tech, and Federal University of Santa Catarina, Brazil. The larger study is a long-term silviculture (three planting densities), site (North Carolina Coastal Plain, Virginia Piedmont, and Brazil), and genetic (six genotypes) experiment in efforts to further understand P. taeda physiology. This Master Project focuses on the Virginia site intending to assess the variation in P. taeda water use.

Goals:

• To enhance the understanding of P. taeda physiology.

Objective:

• To understand how P. taeda transpiration is affected by crown architecture and planting density, accounting for variation in environmental parameters (VPD, soil moisture, and light availability), in efforts to answer the following sub questions:

1. Does transpiration vary with genotypes and planting densities?

2. Does transpiration respond to VPD differently with different genotypes and planting densities?

3. Does response to VPD vary with different levels of soil moisture between genotypes and planting densities?

**2 Material and Methods**

**2.1 Study Area**

Three experimental sites were established in the larger study, including one in the Piedmonts (Reynolds Homestead Center, Virginia, northern edge of P. taeda range), one located on the coastal plain (Bladen lakes, NC, a typical P. taeda site), and one far away from P. taeda range (Renova Forest, Brazil). The data analyzed in this MP solely came from the Piedmont site in Virginia. Although slightly outside of the northern range of P. taeda, the species has established successfully in the Piedmont.

**2.2 Data Source & Experiment Setup**

Data for the experiment was provided by USFS Research Biological Scientist Chris Maier (my additional MP advisor). The experiment was designed as a block plot with a split-split plot design replicated four times (four blocks). Silviculture is the main plot, and spacing and genetic entry are the split plots (Albaugh et al., 2018). Silviculture treatments include two densities of planting: high planting density at 750 trees per acre (TPA) and low planting density at 250 TPA. Each high density plot measures a total of 404.43 m^2 (18.3 \* 22.1 m) and each low density plot measures 134.505 m^2 (18.3 \* 7.35 m).

Within each block contains eight plots of different treatment combination (one clone planted at one density). The experiment of the measured block was divided into four systems and was set up as the chart below:

Table 1. Experimental Setup

|  |  |  |
| --- | --- | --- |
| System | Genotype (crown architecture variation) | Density (trees/acre) |
| 1 | C4 | 750 |
| OP | 250 |
| 2 | C4 | 250 |
| OP | 750 |
| 3 | C2 | 250 |
| C3 | 250 |
| 4 | C3 | 750 |
| C2 | 750 |

Where according to Carbaugh (2015), OP stands for an open-pollinated family and C refers to clones. C3 is considered narrow crown genotype whereas C2 and C4 are considered broad crown genotypes. The narrow crown genotype possesses smaller branch diameter, branch length, and crown volume than the broad crown genotypes. Within the broad crown genotypes, C4 has a slightly larger crown volume than C2. The OP family share similar branch characteristics to the broad crowned clones with a crown volume in between of broad and narrow crowned clones. Seedlings were planted in 2009.

Sapflux was measured using Granier ‘s thermal probe at stand age 8-9 (2016-2017) for block ?. We used data during the growing season (June-September) of 2017 because data of 2017 was relatively complete; and during growing season, trees are the most active and generates the most drastic sapflow patterns that best represents individual tree characteristics (Lyu et al., 2020) Briefly, within each treatment plot, eight trees were selected for sapflux measurement. Each tree had a pair of sapflux probes inserted from 0-20 mm (shallow) on the north and south side of the tree. Two of the trees in each plot had an additional probe inserted from 20-40mm (deep). Sapflux was measured every 30 seconds and then averaged over a 15-minute time step.

Tree diameter (cm) was measured for all trees at the beginning and the end of each experimental year.

Specific soil moisture (% water per volume soil) was available for block ? for each treatment plot. Additional data related to the weather parameters were obtained from on-site weather station.

**2.3 Data Preparation**

**Data Cleaning**

The 15-minute-interval raw k-values generated from thermal probes were transformed into sap flux density using Granier’s Equation (Fd = 119 \*k^1.231). Data was visually presented and checked for error and interesting patterns.

**Gap-filling**

The smallest gaps (<5 entries) in the raw data were interpolated. Relatively small gaps (<48 entries, or half day) of individual probes were filled in with simple linear regression between probes for each 15-minute entry. Gaps larger than 48 entries were gap-filled after calculating daily sums using simple linear regression between probes for each daily sum.

**Sapwood Area**

Diurnal tree diameters were calculated using the set of equations as:

dbhrel = 1 / (1+(b0\*(exp(-b1\*DOY))))

DBH = ((DBH1-DBH0)\*dbhrel)+DBH0

Where: b0=61.3445, b1=0.0235; dbhrel is an explanatory variable standing for a tree’s relative size (Vastaranta et al., 2011); DOY stands for day of year; DBH is the DBH at any given time; DBH0 and DBH1 stand for DBHs at different time points. The calculated diurnal tree diameters were then transformed into sectioned sapwood area corresponding to probe depths: outer 20mm, 20mm-40mm, and >40mm areas.

**Sapflow**

In sapflow calculation, sapflux measurements were multiplied by specific sapwood area, where the outer probes measure the outer 20mm of sapwood and the inner probe measures the inner 20-40mm. When sapwood diameter exceeds 80mm, sapflux of the inner most sapwood area was considered half of the 20-40mm area sapflux.

The transformed sapflux (g H2O/m-2/s-1) of individual data points was scaled up temporally and spatially as sapflow values (L or kg H2O). The 15-minute entries were summed up for each tree across daytime when Photosynthetic Active Radiation (PAR) is above zero. They were also scaled up to stand level transpiration using plot-specific sapwood area.

**Soil Moisture**

Soil moisture was transferred in Relative Extractable Water (REW) to achieve normalization. REW was calculated as the ratio of the difference between each soil moisture entry and minimum soil moisture during our time of interest, and the difference between maximum soil moisture and minimum soil moisture ((soil moisture-minimum soil moisture)/(maximum soil moisture – minimum soil moisture), Granier et al., 1999).

**2.4 Data analysis:**

**3 Results**

**4 Discussion**

State the Major Findings of the Study

Explain the Meaning of the Findings and Why the Findings Are Important

Relate the Findings to Those of Similar Studies

Consider Alternative Explanations of the FindingsState the Clinical Relevance of the FindingsAcknowledge the Study’s LimitationsMake Suggestions for Further ResearchGive the “Take-Home Message” in the Form of a Conclusion

Conclusion

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