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

by

[Azura Liu]

[Ram Oren, Christopher Maier]

*Masters project proposal submitted in partial fulfillment of the*

*requirements for the Master of Environmental Management degree in*

*The Nicholas School of the Environment of*

*Duke University*

[I/WE] certify the following:

Does this proposed MP involve human subjects research? \_\_\_ Yes \_\_Ⅹ\_ No

If yes, has an approved IRB protocol been obtained? \_\_\_ Yes \_\_\_ No

Does this proposed MP involve the use of animals in research? \_\_\_ Yes \_\_Ⅹ\_ No

If yes, has an approved IACUC protocol been obtained? \_\_\_ Yes \_\_\_ No

Does this proposed MP involve signing a non-disclosure agreement? \_\_\_ Yes \_Ⅹ\_\_ No

If yes, does the advisor have a signed copy? \_\_\_ Yes \_\_\_ No

Student Signature: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date: \_\_\_\_\_\_\_\_

Advisor Signature: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date: \_\_\_\_\_\_\_\_

**Part I: Scope of Work**

Introduction

Forest lands are shrinking rapidly due to anthropological development, primarily losing to agricultural land conversion necessary for growing population (FAO & UNEP, 2020). Aside from the biological, ecological and spiritual values lost along with deforestation, the world continues to increase its demand for wood (FAO, 2009). The total volume of forest growing stock, however, remains relatively stable over the last three decades (FAO, 2020), meaning forests are required to either be more densely stocked or possess higher productivity. As the most abundant softwood species in the U.S. and the most commercially important timber species in the South (Brender, Belanger, & Malac, 1981), loblolly pine (*Pinus taeda,* or *P. taeda*) supports the timber industry generously and contributes abundant above-ground biomass at 2.1 billion tons in 2017 (Oswalt et al., 2019). Numerous theories have been developed intending to explain the variation of *P. taeda* productivity (Samuelson et al., 2013; Shimizu & Sebbenn, 2008) in the hope of finding efficient methods of enhancing *P. taeda* yield. The factors considered in previous studies include but not limit to: stockability (DeBell, Harms, & Whitesell, 1989), management intensity (Borders & Bailey, 2001), spacing regimes (Cardoso et al., 2013), genetic variation (de Oliveira et al., 2018), and previous land use (Souza et al., 2022). There has not been a definite answer to the question yet. This Master’s Project (MP) intends to assess the variation between *P. taeda* productivity from a perspective less frequently discussed: water use.

Water use efficiency (WUE) is interpreted as the carbon assimilated by plants per unit of water used during this process (Briggs & Shantz, 1913):

In other words, with other factors holding constant, higher WUE can achieve the same productivity with less water. Both water availability and the plant’s ability to conduct water are essential for growth (Bréda et al., 2006). Water availability is a critical consideration when we are facing the challenge of climate change. While scientists had hopes that elevated atmospheric CO2 (Ehlers et al, 2015), increasing solar radiation (Chapin et al., 2002; Guoju et al. 2013) and extended growing season (Xiao et al., 2013; Gillman et al., 2015) would raise plant productivity, extreme weather events and their spatial variability have brought great uncertainty (Reyer et al., 2016). Zhao and Running (2009) estimated a drought-induced reduction of 0.55 petagram carbon in global NPP from 2000 to 2009. Drought-induced additional hydraulic stress such as heat stress and water deficit (Hatfield et al., 2011). Although elevated CO2 and water deficit stress can promote WUE, the system is commonly shut down by accompanied heat stress (Lawson & Blatt, 2014; Lopes et al., 2011). On the other hand, the conductance of water flow varies with each tree’s morphology and physiology (Kimball, 2007), thus manipulating transpiration can be a potential solution to combat climate change and enhance yield. By manipulating leaf morphology (Craufurd et al., 1999), crown architecture (Ritchie, 1972), root structure (Comas et al., 2013), etc., we can achieve higher WUE directly (needs less water) or indirectly (e.g. less susceptible to heat stress). Selecting and breeding water use efficient genotypes has gained substantial success in the field of agriculture (Yoo et al., 2009; Siahpoosh & Dehghanian, 2012; Wright, Nageswara, & Farquhar, 1994) but is slowly coming on for trees that have longer lifespan.

Goals & Objectives

**Goals**:

* The ultimate goal of this project is to contribute to the understanding of the physiological mechanisms explaining difference in growth and carrying capacity of *P. taeda*.
* Within this project, our goal is to examine how differences in crown architecture among clones and spacing influenced tree water use and water use efficiency (WUE).

**Objectives**:

* To clean and eliminate errors from original data.
* To scale up individual data points spatially (individual tree and stand) and temporally (day, night, 24-hour, etc.).
* To compare sap flux data of *P. taeda* from experimental plantation, accounting for different treatments, genotypes, and environmental parameters including but not limited to vapor pressure deficit, photosynthetically active radiation, and soil moisture.
* To relate water use and WUE patterns to stand-level productivity within each treatment.

Methods and Sources of Support

Plants are generally perceived to have the best chance of survival within their native range because they have adapted to the local climate well and have formed stable bonds with local communities (Tallamy, 2007). Although native to the southeastern U.S., *P. taeda* exhibits significantly higher net primary productivity (NPP) in Hawaii (Samuelson et al., 2013) and Brazil (Shimizu & Sebbenn, 2008). Numerous theories have been developed intending to explain such phenomenon. The factors considered in previous studies include but not limit to: stockability (DeBell, Harms, & Whitesell, 1989), management intensity (Borders & Bailey, 2001), spacing regimes (Cardoso et al., 2013), genetic variation (de Oliveira et al., 2018), and previous land use (Souza et al., 2022). There has not been a definite answer to the question yet. This MP exists as part of a larger study 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, site, and genetic experiment in efforts to further understand *P. taeda* physiology.

**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 Piedmonts.

**Data Source & Experiment Setup**

USFS research biological scientist Christopher Maier, also my additional MP advisor, has provided the data that make this project possible.

The experiment is a block plot with a split-split plot design replicated 4 times; silviculture (low/high intensity) is the main plot and spacing and genetic entry are the split plots (Albaugh et al., 2018). With a total of eight plots, each plot contains one treatment (one clone planted at one density). The experiment was set up as the chart below:

|  |  |  |
| --- | --- | --- |
| 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 |

Within each treatment plot, eight trees are sapflux trees inserted with a pair of probes inserted from 0-20 mm (shallow) on the north and south side of the tree; two trees in each plot had an additional probe inserted from 20-40mm (deep).

The stand was planted in 2009, and the data for this MP were collected continuously for two years, at stand age 8-9.

Additional data related to the weather parameters were either directly recorded from the site or obtained from on-site weather station.

**Workflow**

Data Cleaning (completed): Raw k-values were provided, and they required further transformation into sapflux with Granier's equation (Fd = 119 \*k1.231). Data have been visually presented and checked for error and interesting patterns.

Data analysis (in progress): The transformed sapflux values will be correlated with weather parameters and differentiated statistically. The raw tree measurements will then be converted into wood volume. Finally I will test and conclude how water use affect growth differently among treatments.

Analysis phases: Phase I of the analysis is to find and test the best approach with one month’s data (nearly completed). Phase II is to expand this approach to a larger range of data—as large as time permits.

Support: Data would be analyzed primarily using Microsoft Excel and R. Limited python will be applied.

Expected Results and Format of Report

The study aims to model treatment differences in terms of *P. taeda* water use, in the hope of contributing to further studies within the larger project. This study will identify water use efficient *P. taeda* genotype(s) and help direct future studies that ultimately try to explain the differences in *P. taeda* productivity between locations.

The result of this project will be delivered in the format of a report and a presentation. The report shall be written professionally and scientifically; it will be submitted to the Nicholas School as the final MP report. A presentation will be given to the Nicholas School audiences and/or any individual interested in such topic during the MP Symposium on December 1st, 2022. The presentation shall be relatively succinct and intelligible to the general public, including sufficient background information and appealing graphic presentations of the study outcome.

The anticipated outcome, in addition to MP, is a potential manuscript submitted to a top professional journal.

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Faculty

**Ram Oren** (primary advisor), Nicholas School of the Environment & Pratt School of Engineering, Duke University

**Christopher Maier** (additional advisor), Research Biological Scientist/Team Leader at Southern Research Station, U.S. Forest Service

**Part II: Project Timeline**

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| --- | --- |
| *Time* | *Action/Due* |
| Academic year 2020-21  *Initial setup* | * Accepting project as assistantship * Developing advisory team and plan for MP * Complete supplemental reading related to the project:   + Previous publications on the project   + Additional papers on tree physiology (especially on sap flux) * Understand study design and background information * Data cleaning |
| Fall 2021  *Analysis* | * Data exploration: visually present the data and look for interesting patterns or abnormities * Narrow down analysis direction and statistical methods; devise the scope of MP * Project prospectus due on 10/29 * Testing out devised analysis on part (one month) of the data |
| Spring 2022  *Analysis* | * Work plan due on 2/1 * Expanding analysis to larger range of the dataset as much as I can. Ideally perform the analysis on an entire year (maybe two!) of data * Project status presentation |
| Fall 2022  *Wrap-up and writing* | * Wrap-up analysis * Written draft of Final Report due on 9/30 * Develop good visual presentations of the study outcome * Revised draft due on 10/31 * 10-Line Abstract due to Student Services on 11/18 * Submission of final MP to iThenticate for scanning on 11/28 * Present MP (Symposium) on 12/1 * Final MP due on 12/8   + Upload to DukeSpace   + Submit signed executive summary to Student Services via the DukeBox Upload Window |

**Part III: Team Charter**

Team Roles and Responsibilities

|  |  |  |
| --- | --- | --- |
| Member | Role/Title | Responsibilities/Expectations |
| Azura Liu | *MEM-ESC/MF Student* | * Conduct analysis and complete the MP * Schedule meetings and ensure communication |
| Ram Oren | *Master's Advisor,*  *NSOE Professor/Faculty* | * Primary advisor * Assist student with administrative requirements * Provide guidance on study design and direction * Give feedback and insight on analysis completed by student |
| Christopher Maier | *Member of the Advisory Team,*  *USFS Research Biological Scientist* | * Additional advisor * Supply data and background information necessary for the project * Provide guidance on study design and direction * Give feedback and insight on analysis completed by student |

Regular Meeting Schedule

The MP team meets on a weekly to bi-weekly basis based on the progress student has made. Student meets one or both advisors according to each member’s schedule.

Team Expectations

Team members will communicate efficiently through email, the primary method of communication. Meetings are conducted primarily via Zoom, but the team tries to meet in person at NSOE or USFS research station as possible.

Team Purpose and Mission

The team aims to complete the MP in reasonable timeframe. Beyond the MP requirement, we will take advantage of the marvelous dataset and explore as much as possible. The outcome of the study shall aid understanding in loblolly pine physiological mechanisms and production.

**Top Prioritieis and Goals**: As someone who never performed research before, the student takes the project as a valuable learning experience, understanding the logic and obtaining necessary skills for research as diving deeper. The top priority and goal of the advisors is to provide appropriate guidance and advice so student can learn efficiently and yield a high-quality MP in time.

Team Cohesion and Conflict Resolution

When conflicts emerge, team members will communicate honestly and openly regarding responsibilities. If there are disagreements in analysis approaches, statistical methods, etc., the team members will each present their thoughts and decide on what is best. Additional help from other faculties (e.g. Statistics professor) can be sought if agreement cannot be achieved.

**Additional Resources:** available at Duke Graduate School Student Resources (<https://gradschool.duke.edu/student-life/student-resources>).