EFFECTS OF PRESCRIBED FIRE ON LEAF FUNCTION, NON-STRUCTURAL CARBOHYDRATE FORMATION, AND NUTRIENT ALLOCATION IN *PINUS ECHINATA* STANDS

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Abstract

Shortleaf pine (*Pinus echinata* Mill.) is a fire resilient timber species and its presence on the landscape drives the continuation of unique xeric forest habitats. It also has a variety of unique phenotypic traits that make it more resilient to fire than other pine species within its range. The dominance of *P. echinata* has declined over the past century, and this is attributed, in part, to landscape-scale exclusion of wildland fire. Common restoration strategies for *P. echinata* include prescribed burning, but the functional and physiological responses of this species to varying fire intensity and seasonality are not fully understood. In this study, we will assess fluctuations in *P. echinata* phenotypic trait expression and non-structural carbohydrate formation in response to heating duration and burn seasonality. Our results will help to better contextualize *P. echinata* responses to ecological disturbance and inform the use of prescribed fire as a management tool for the restoration of xeric pine-dominated ecosystems.

*This paper is a partial report for this study which is currently in progress with anticipated completion by May 2026.

1. Introduction

Long-term climate forecasts for the southeastern United States (US) project increased ambient temperatures and precipitation east of the Mississippi River, but with greater variability in precipitation timing and increased drought frequency (Mitchell et al., 2014; Rocca et al., 2014). These climate shifts are tied to increased risk for future wildfires (Mitchell et al., 2014), and they are also a driver of mesophication, a landscape-scale ecological transition which has driven major shifts in forest composition and structure in the eastern US (Alexander et al., 2021; Nowacki and Abrams, 2008). Characterized by an emerging dominance of mesic or moist-site vegetation, mesophication has also been attributed to exploitative high-yield timber harvesting practices (Ryan et al., 2024), increased deer herbivory (Hanberry and Faison, 2023), and wildland fire suppression and exclusion (Nowacki and Abrams, 2008). While xeric or dry-site species often possess adaptations to fire, such as thick bark or resprouting potential, mesic species are more commonly fire-intolerant (Abrams, 1992; Keeley and Pausas, 2022). As a result, the restoration of historic fire regimes through prescribed burning has long been proposed as a management priority in the southeastern US with the dual purpose of reducing wildfire risk by consuming hazardous fuel and reversing mesophication by promoting pyrophytes. *P. echinata* is one such pyrophyte; largely attributed to fire exclusion, the dominance of this species east of the Mississippi River has decreased by more than 50% since 1980 (Guldin and Black, 2018). The optimal fire return interval for promoting and maintaining *P. echinata* dominance is thought to be 8-11 years (Stambaugh et al., 2007), and several evolutionary adaptations may provide it with a competitive advantage in frequently-burned environments, such as the ability to resprout following topkill (Clabo and Clatterbuck, 2019) and development of thick, platy bark which protects the cambium from heat damage (Reifsnyder et al., 1967). Restoration of *P. echinata* via the combination of planting and burning has become a management priority, especially on National Forests (Guldin, 2019), but the functional and physiological responses of this species to fire have not been fully described.

A disturbance response mechanism of particular interest in *P. echinata* is the production and storage of non-structural carbohydrates (NSCs), which are primarily composed of non-soluble sugars and starches (Hartmann and Trumbore, 2016). Soluble sugars typically support functions associated with plant growth, but starch reserves are more commonly associated with post-disturbance regrowth and recovery (Chapin III et al., 1990; Mooney and Hays, 1973; Paula and Ojeda, 2009). NSC storage and utilization may exhibit short-term variation due to changes in growth conditions (e.g. shifting light availability due to changes in cloud cover) (Furze et al., 2019; Richardson et al., 2013; Zhu et al., 2012) as well as due to seasonality (Reed and Hood, 2024), but disturbance such as fire may drive long-term, gradual shifts in which NSCs are produced and how they are utilized (Paula and Ojeda, 2009). For example, research suggests that species prone to resprouting after top kill also exhibit greater concentrations of starches in root tissues (Bell and Ojeda, 1999; Knox and Clarke, 2005; Pate et al., 1990). Burning of ponderosa pine (*P. ponderosa*) was associated with gradual depletion of NSCs, most severely in trees which eventually died; such declines were strongly tied to crown injury (needle scorch and bud kill) (Reed and Hood, 2024). NSC reserves are especially important to post-fire recovery as they support plant functionality when leaves are injured or destroyed, reducing the capacity for direct support of functions like growth and respiration via photosynthesis (Chapin III et al., 1990; Iwasa and Kubo, 1997; Schutz et al., 2009). In cases where crown damage is minimized, such as in low-intensity surface fires where crowns are tall enough to escape direct heating, damage to vascular and cambium tissues may still occur and impede translocation of resources throughout the plant (Varner et al., 2009).

Our study will evaluate variation in NSC storage and utilization alongside functional trait expression in *P. echinata*, in order to:

1) Determine how fire regime factors (stand age, heating duration, fire seasonality) interact with NSC storage and utilization, especially where crown damage is minimized;
2) Assess fire regime and NSC storage as drivers of post-disturbance functional trait expression (e.g. leaf area, bark thickness) and tree mortality.

2. Methods

2.1 Study Area

This study will take place on two differently-aged *P. echinata* plantations, each containing approximately 150 stems, which are located at the Reynolds Homestead Forest Resources Research Center, Critz, Virginia (“Reynolds”) and at the Cradle of Forestry, Pisgah National Forest, North Carolina (“Cradle”). *P. echinata* stems at Reynolds are intermixed with similarly aged loblolly pine (*P. taeda*) and the stand has never been thinned or burned. The Cradle site is a pure *P. echinata* stand. In January 2020, stems at the Cradle plantation were clipped, burned, or left undisturbed. Table 1 includes the planting year for each stand.

Stand	Year Planted
Reynolds Homestead	2017
Cradle of Forestry	2009

Table 1: Pine plantation planting years.

2.2 Experiment

At each plantation, *P. echinata* stems will be randomly assigned a treatment combination based on the following factors:

1) Burn seasonality (dormant season or. growing season)
2) Heating duration (0s, 30s, 60s)

Growing season burns will be conducted in June 2024 and dormant season burns will be conducted in February 2025. Stems will be burned with a novel basal torching approach, which was also utilized at the Cradle in 2020. The base of each stem will be heated directly with a Red Dragon VT-2 propane torch, which will minimize crown damage and allow for direct manipulation of heating duration and simulate the variation in residence time which occurs during real prescribed fires. Insulating material (made of aluminum and silica) will be placed around the base of each stem during burning to contain radiant heat. To minimize weather-induced variation in NSC storage, stem burning at each plantation will take place on the same clear-weather day, between 9 am and 3 pm.

For each burn day, descriptive data will be collected at six time intervals: less than one week prior to burning and post-burn at 0, 5, 30, 60, and 120 days. Each tree will be described in terms of diameter at breast height (1.37 m), branch density, crown volume, tree height, aspect, elevation, and slope.

2.3 Data Collection

We will assess function of shortleaf pine using traits that can be defined as either “conservative” or “acquisitive”: specific leaf area, leaf toughness, leaf dry matter content, chlorophyll, nitrogen, and phosphorous concentrations, crown volume, branch density, diameter and height. We chose these traits because they can provide important information about how resources are utilized (Carreño-Rocabado et al., 2012). We will also assess bark thickness and density. For leaf variables, we will follow protocols for functional trait assessment in plants, as described by Pérez-Harguindeguy et al. (2013). Needles will be removed with clippers from a central limb. Crown volume and height will be measured with a sonic hypsometer (Vertex Laser Geo, Haglof, Sweden), and stem diameter will be measured manually. To assess bark thickness and density, bark samples will be removed from each stem using an increment borer, 30 cm above the base of the stem. We will then use a microscope to measure the depth of the bark sample, and weigh the sample to determine its density. For NSCs, starch and non-soluble sugars will be measured in bark and needle tissue as described by Richardson et al. (2013).

To describe the soils and growth environment, we will take one 15 cm soil sample within one meter of each tree, using a soil sampler with a diameter of 3 cm. Samples will be divided by depth (0-5 cm, 5-10 cm, 10-15 cm) and we will assess nutrient content (C, N, P, K), salinity, acidity, and bulk density at each depth.

3. Anticipated Results

Based on previous research, we hypothesize that increased heating duration will drive cambial damage and will be associated with gradual declines in NSC storage. The length of basal torching will correspond to reduced growth relative to controls and increased utilization of NSCs, especially in root tissue. NSC utilization will also be associated with increased bark thickness. At the Cradle of Forestry plantation, additional torching will lead to reduced mortality and sprouting compared to the 2020 torching. We also anticipate that increased heating duration will correlate to functional trait expression that favors nutrient acquisition with lower construction costs, such as increased leaf and crown area and reduced leaf dry matter content. Because NSC storage has been found to increase at the start of the growing season (Reed and Hood, 2024), we hypothesize that negative responses to fire (e.g. mortality, inhibited growth) may be reduced in the growing season.

4. References

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