EFFECTS OF CROWN SCORCH ON LONGLEAF PINE FINE ROOTS[1]

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Abstract-Photosynthate production is reduced by foliage loss. Thus, scorch-induced decreases in the leaf area of longleaf pine (*Pinus palustris* Mill.) may reduce photosynthate allocation to roots. In this investigation the root carbohydrate concentrations and dynamics of longleaf pine after two intensities of prescribed burning were monitored. In September 1996, 65-year-old longleaf pine were burned. Plots of 10 trees were established in two patches each of nonscorched and scorched trees. Root carbohydrate concentrations and dynamics were monitored May 1997 through December 1998. Root sucrose and starch concentrations were lower on the scorched plots than on the nonscorched plots. One year after burning, fine root mass density and secondary root development were reduced in response to crown scorch. These results indicate that prescribed fires that cause crown scorch may reduce photosynthate allocation to roots. Further research is needed to determine the impact of fire intensity on root system growth and function.

INTRODUCTION

Maintenance of mature longleaf pine (*Pinus palustris* Mill.) ecosystems generally requires recurrent burning at a 2- to 4-year interval (Franklin 1997, Landers and others 1995). Before intensive clearing of the longleaf pine forests, this requirement was met by the natural occurrence of frequent fires (Franklin 1997, Landers and others 1995). However, with the industrial development of the Southeastern U.S., natural forest fires were prevented and prescribed fire was not considered a viable forest management tool (Landers and others 1995).

In the absence of frequent fire, loblolly (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm. var. *elliottii*) grow in association with longleaf pine (Brockway and Lewis 1997, Landers and others 1995). Because the nursery production and establishment of loblolly and slash pine were less difficult and costly than that of longleaf pine, most harvested longleaf pine forests were naturally or artificially regenerated with loblolly and slash pine (Landers and others 1995, Outcalt 1997).

New approaches in seedling culture, site preparation, and release are currently used to successfully regenerate longleaf pine (Barnett and others 1990, Boyer 1989, Hatchell 1987, Loveless and others 1989). With improvements in longleaf pine management tools, this species competes well from a productivity standpoint with loblolly and slash pine (Earley 1997, Franklin 1997, Outcalt 1997).

Comparisons of longleaf pine productivity among stands that are managed with and without prescribed fire have been made (Boyer 1987, Brockway and Lewis 1997). Although it has been reported that routine prescribed fire did not negatively affect longleaf pine productivity (Brockway and Lewis 1997), Boyer found that the growth of longleaf pine was reduced by regular burning (Boyer 1983, 1987; Landers and others 1995).

Decreases in longleaf pine productivity on routinely burned sites may be attributed to the intensity and timing of prescribed burning relative to the seasonal pattern of carbon allocation in trees. Glitzenstein and others (1995) introduce this concept in their discussion of why season of burn affects the dynamics and composition of southeastern forests. At the time of a prescribed fire, branch phenology, the role of existing foliage as a carbon source, and the vulnerability of existing foliage to scorch-induced, premature senescence may be critical factors affecting stand productivity.

In longleaf pine ecosystems with water and mineral nutrient deficits, sufficient energy must be available for the advancement of new roots if soil resource requirements are to be met. On these sites, a chronic reduction in the availability of carbohydrates for root metabolism may limit soil resource uptake, root system expansion, and subsequently, stand productivity. We hypothesize that the scorch-induced, premature senescence of foliage after a prescribed fire reduces the availability of carbohydrates for root metabolism and subsequently alters fine root dynamics and secondary root development.

MATERIALS AND METHODS

Study Location

The study is located in a 65-year-old longleaf pine stand with a basal area of approximately 19.5 m^2 per ha on the Calcasieu Ranger District of the Kisatchie National Forest, Rapides Parish, Louisiana (Section 12, T.2N, R.2W). The study site is characterized by two topographically distinct areas that correspond to the soil series at the location. The soils are a Ruston fine sandy loam (siliceous, thermic, Typic Paleudult) with a 1 to 3 percent slope and a Smithdale fine sandy loam (siliceous thermic, Typic Paleudult) with an 8 to 12 percent slope.

Study Design

In September 1996, the stand was prescribe burned using a series of strip-head fires. At strip interfaces, the crowns of longleaf pine trees were severely scorched. By late fall, the scorched trees were nearly defoliated. The study was established in a randomized complete block design with one plot of 10 trees in a nonscorched and scorched region of two blocks. Blocks were identified based on topography.

Field and Laboratory Procedures

At l- to 2-month intervals May 1997 through May 1998 and in December 1998 one soil core (6.2-cm diameter) was extracted from the 0- to 20-cm depth of the soil using a metal coring device. The cores were collected from random locations within 2 m of each tree (Ruark 1985). Within 1.5

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hours of core collection, roots (≤5-mm diameter) were elutriated from soil cores and composited by plot (Smucker and others 1982).

Pine roots, 2 to 5 mm in diameter, were removed from the composited root samples and separated into three groups. Two groups consisted of one root each, and the third group consisted of the remaining roots. Roots were placed in paper bags and frozen in dry ice.

Frozen roots were lyophilized and ground (40-mesh). Root sucrose, glucose, and starch concentrations were quantified using a modification of the procedure of Jones and others (1977). Starch and hexose (glucose + fructose) were extracted from 25 mg of ground tissue and enzymatically converted to glucose.. Glucose was measured by the glycolytic production of reduced nicotinamide adenine dinucleotide phosphate (NADPH). The NADPH was measured spectrophotometrically at 320 nm. Carbohydrate concentrations are expressed as mg per g ash-free dry weight.

The remaining composited fine roots were placed in plastic bags and refrigerated until processing. Initially, these roots were separated into pine and nonpine fractions. The nonpine fraction was discarded. The pine fraction was separated into two categories: (1) live fine roots and (2) dead fine roots. Live fine roots were succulent and pliable and had good adhesion between the stele and cortex. Dead fine roots were dark colored and flaccid or brittle and had poor adhesion between the stele and cortex. Live fine roots were further separated into two categories: (1) primary roots and (2) secondary roots. Primary roots were characterized as new roots plus roots that were ≤ 1 mm in diameter and nonwoody in appearance. Secondary roots were characterized as either ≤1 mm in diameter and woody in appearance, or >1 but <2 mm in diameter. Roots in each category were dried (70 °C) to equilibrium and weighed. Weights of roots that were 2 to 5 mm in diameter were added to secondary fine root weights to obtain weights of secondary roots ≤5 mm. Data are expressed as either mass density (g per dm^3 soil volume) or percentage of. mass density.

In December 1998, foliage from the first flush of 1998 in the upper crown of three randomly selected trees per plot was collected, lyophilized, and ground (20-mesh). After sulfuric acid/cupric sulfate digestion, foliar concentrations of phosphorus (P) were measured by colorimetry (John 1970) and foliar concentrations of potassium (K), calcium (Ca) and magnesium (Mg) were measured by atomic absorption spectrophotometry (Isaac and Kerber 1971). Foliar nitrogen (N) concentrations were quantified using a CNS-2000 Elemental Analyzer (Leco Corporation, St. Joseph, Ml).

Statistical Analysis

Data at each measurement interval were transformed to their natural logarithms as needed to establish normality and evaluated by analysis of variance using a randomized complete block design with two blocks. Main effects were considered statistically significant at probabilities (Pr) 10.05 unless noted otherwise.

RESULTS

Root Carbohydrate Concentrations

Root sucrose and glucose concentrations averaged 16.4 and 35.6 mg per g, respectively, and were seasonally

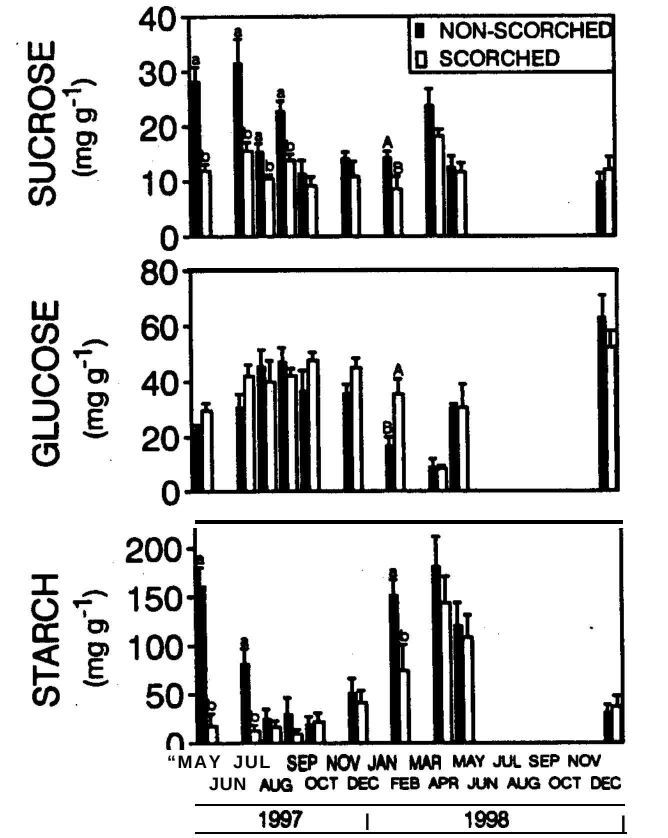

Figure 1-Longleaf pine root sucrose, glucose, and starch concentrations (mg per g) 8 to 28 months after a prescribed bum that caused severe crown scorch in September 1996. Means associated with a different lower or upper case letter are significantly different at Pr≤ 0.05 or 0.10, respectively.

variable. Root starch concentration exhibited a seasonal pattern with a maximum in late winter through spring (February-May) (145 mg per g) and a minimum in mid-summer through early winter (August-December) (28 mg per g) (fig. 1).

In May and July 1997, root sucrose and starch concentrations were significantly reduced in response to crown scorch in September 1996 (fig. 1). Root sucrose concentration continued to be significantly less on the scorched plots in August and September 1997 when compared to the nonscorched plots. Root glucose concentration in 1997 was not significantly affected by crown scorch. In February 1998, root sucrose and starch concentrations were significantly lower and root glucose concentration was significantly higher on the scorched plots than on the nonscorched plots.

Root Mass Density

Total (live + dead) pine fine root mass density May 1997 through April 1998 was relatively constant and averaged 2.7 g per dm^3 (fig. 2). During the 8- to IQ-month period after the prescribed bum, pine fine root mass density consisted of approximately 28 and 72 percent dead and live roots, respectively. In September 1997, 1 year after prescribed burning, total and live pine fine root mass densities were

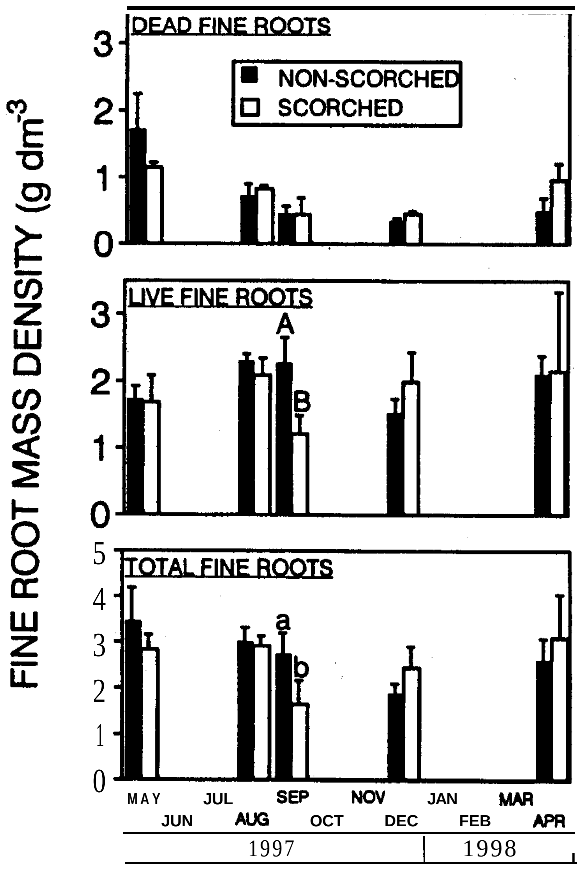

Figure 2—Longleaf pine fine root mass density (g per dm^3) 8 to 19 months after a prescribed bum that caused severe crown scorch in September 1996. Means associated with a different lower or upper case letter are significantly different at Pr ≤0.05 or 0.10, respectively.

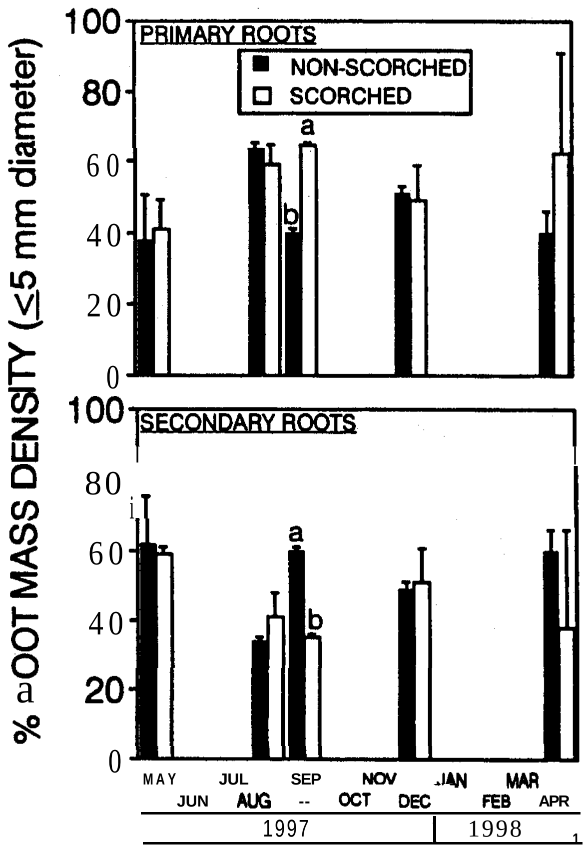

Figure 3-Percentage of longleaf pine root mass density (≤5-mm diameter) that appeared to exhibit primary and secondary development 8 to 19 months after a prescribed bum that caused severe crown scorch in September 1996. Means associated with a different lower case letter are significantly different at Pr r0.05.

significantly lower in response to crown scorch. This response did not occur on the other measurement dates in May 1997 through April 1998.

Approximately 51 and 49 percent of the live pine root mass density (≤5-mm diameter) exhibited primary and secondary growth, respectively, during May 1997 through April 1998 (fig. 3). In September 1997, the percentage of live pine root mass density that exhibited secondary growth was significantly reduced in response to crown scorch. This response did not occur on the other measurement dates in May 1997 through April 1998.

Foliar Mineral Nutrient Concentrations

In December 1998, approximately 27 months after prescribed burning, foliar mineral nutrient concentrations were not significantly affected by crown scorch. Foliar concentrations of N, P, K, Ca. and Mg on all plots averaged 8.8, 0.58, 3.8, 1.7, 0.78 g per kg, respectively.

DISCUSSION

Frequent prescribed fire has been associated with a reduction in longleaf pine productivity (Boyer 1983, 1987; Landers and others 1995). Growth reductions could be attributed to fire-induced deterioration of soil quality. However, Boyer and Miller (1994) found that biennial prescribed fire reduced growth in a longleaf pine forest but did not affect soil fertility. Burning did reduce soil pore space and plant-available water holding capacity, but the authors expressed skepticism that this was a major cause of growth reductions.

Perhaps a reduction in mineral nutrient absorption, rather than soil fertility, is the mechanism by which fire decreases longleaf pine productivity. In our study, concentrations of foliar N and P were 10 and 33 percent less, respectively, than the threshold between sufficiency and deficiency for slash pine (Allen 1987). These findings were not unexpected because longleaf pine ecosystems are generally characterized by low soil fertility (Landers and others 1995). In these environments, root system expansion into under-exploited soil is critical for the uptake of nonmobile mineral nutrients such as P. By causing the premature senescence of foliage, prescribed fire may have reduced the amount of photosynthate allocated to the root system and subsequently decreased root growth and soil resource uptake.

Johansen and Wade (1987) found that scorch-induced, premature senescence of 25-year-old slash pine foliage in

January led to a reduction in tree growth for the next two growing seasons. The greatest amount of growth inhibition occurred when the trees were nearly defoliated. However, growth reductions were observed even with the loss of as little as 10 percent of the foliage. Although we did not quantify leaf areas after prescribed burning, we observed a distinct reduction in leaf area in the crowns of the scorched trees when compared to the nonscorched trees within 2 months after burning. Crown scorch in September 1996 accelerated the natural senescence of the remaining 1995 foliage and resulted in the premature senescence of a large portion of the 1996 foliage. In conjunction with premature foliage senescence, we observed a 47 percent decrease in root sucrose concentration May through September 1997 and an 66 percent reduction in root starch concentration May through July 1997.

In addition to decreases in root sucrose and starch concentrations, crown scorch was associated with a 47 percent reduction in live flne root mass density in September 1997. At the same time, a smaller proportionof live root mass density (&-mm diameter) was classified as secondary on the scorched plots when compared to the nonscorched plots. Because root mass density and developmental responses to crown scorch were limited to one of five measurement dates, we question the soundness of this observation. Considerable root variability in soil cores, inadequate sample size, and large measurement errors may have negatively affected the accuracy of our results. Continued study of longleaf pine fine root dynamics in forest stands will require methods that ensure a larger number of samples are collected and measurement errors are minimized. Nevertheless, our results indicate that scorch-induced reductions in leaf area potentially affected longleaf pine root system processes by reducing carbohydrate availability for root metabolism.

Reductions in longleaf pine stand productivity have occurred in response to prescribed fire without notable crown scorch (Boyer 1967). In these situations, growth reductions may be partly attributed to the negative effects of increased soil temperature on the fine root network in the upper portion of the soil profile. Our results do not address the direct effects of soil heating on fine root mortality because root measurements were not initiated until 6 months after burning. We found that crown scorch affected longleaf pine live fine root mass density and secondary root development but did not affect dead fine root mass density 1 year after prescribed burning. Ryan and others (1994) suggested that carbon is preferentially allocated to maintenance respiration rather than to growth. In our study, root sucrose and starch concentrations were reduced but not absent on the scorched plots. Root carbohydrate concentrations on the scorched plots may have been diminished enough 1 year after prescribed burning that root growth ceased, but maintenance respiration was sustained and root mortality was unaffected.

Although the age class of foliage that was directly affected by prescribed burning had naturally senesced by early 1996, reduced concentrations of root sucrose and starch on the scorched plots were still observed in February 1998. In addition to limiting the amount of photosynthate allocated to root growth, scorch-induced, premature senescence of foliage in fall 1996 may have reduced the amount of photosynthate allocated to new flush growth in spring 1997. The consequent reduced photosynthetic capacity of foliage produced in 1997 may have prolonged the period of limited carbohydrate availability for root metabolism beyond 1 year.

Alternatively, reduced concentrations of sucrose and starch in February 1998 may have been caused by more rapid carbohydrate mobilization for root metabolism. In February 1997, lower concentrations of root sucrose and starch on the scorched plots were accompanied by a higher concentration of root glucose. Past research has shown that a greater proportion of fixed carbon is allocated to root system growth than aboveground growth on resource-limited sites (Keyes and Grier 1981, Vogt and others 1983). If the existing root system network on the scorched plots was unable to meet tree-soil resource requirements, rapid transformation of sucrose and starch into glucose may have been a mechanism for accelerated root growth when the soil warmed in spring.

SUMMARY

The restoration of longleaf pine ecosystems in the Southern U.S. is underway. Prescribed fire will probably continue to be a valuable tool in managing these forests. We found that a prescribed fire in September that resulted in the premature senescence of foliage reduced the availability of carbohydrates for longleaf pine root metabolism. One year after burning. reduced root carbohydrate concentrations were associated with a smaller fine root network and proportion of roots that had undergone secondary development. Frequent recurrence of these responses to prescribed fire could reduce the uptake of water and mineral nutrients by roots and subsequently, decrease stand productivity. Further research is needed to determine the regime of prescribed fire that meets forest management goals and minimizes negative effects on leaf area and root system processes.

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