INFLUENCE OF REPEATED PRESCRIBED FIRE AND HERBICIDE APPLICATION ON THE FINE ROOT BIOMASS OF YOUNG LONGLEAF PINE

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Abstract—Photosynthate from mature foliage provides the energy source necessary for longleaf pine (*Pinus palustris* Mill.) root system expansion. Crown scorch caused by repeated prescribed fire could decrease this energy and, in turn, reduce new root production. We conducted a study to assess the root biomass of restored longleaf pine saplings in response to three prescribed fires applied in spring over a six-year period. We observed less pine fine root biomass at the 20- to 30-cm soil depth in response to repeated prescribed fire. Absence of a similar effect at the 0- to 20-cm soil depth suggests root system sink strength at different soil depths could influence the recovery of root growth processes after crown scorch. Observations from this study will be used to refine the experimental methodology of future assessments of longleaf pine root system responses to repeated prescribed fire.

INTRODUCTION

The dramatic loss of longleaf pine (*Pinus palustris* P. Mill.) across southern landscapes between the late 1800s and mid 1900s was attributed to extensive logging, followed by regeneration failure and exclusion of fire as a management tool (Barnett and Dennington 1992, Boyer 1989, Outcalt 2000). Because the native plants and animals of longleaf pine ecosystems are adapted to, and may depend on frequent fire (Brockway and Lewis 1997, Haywood and others 2001, Landers and others 1995, Outcalt 2000), successful longleaf pine ecosystem restoration is dependent on prescribed fire. Recent recognition of fire as a necessary forest management tool in the South (Brockway and Lewis 1997, Brockway and Outcalt 2000, Gilliam and Platt 1999, Haywood and others 2001), and development of successful techniques to regenerate longleaf pine (Barnett and McGilvray 1997, Boyer 1989, McGuire and others 2001, Ramsey and others 2003, Rodríguez-Trejo and others 2003), have stimulated interest in restoring this species to portions of its natural range.

Root system expansion is required for acquisition of water and mineral nutrients, so that the physiological processes controlling tree growth are maintained. Most new longleaf pine root growth occurs in spring before drought-induced soil conditions limit root elongation (Sword Sayer and Haywood 2006). Current photosynthate is the primary energy source for root metabolism (Dickson 1991). Therefore, the amount and physiological activity of mature foliage in spring affect the supply of energy for longleaf pine root system expansion. If prescribed fire and its associated crown scorch reduce leaf area in spring, the amount of energy allocated for root growth may also be reduced. The occurrence and magnitude of this effect, however, depend on the extent of crown scorch and the ability of trees to reestablish leaf area. Our objective was to monitor the root biomass of longleaf pine saplings in response to three prescribed fires applied in spring over a six-year period. It is hypothesized that longleaf pine root biomass is reduced by repeated prescribed fire.

MATERIALS AND METHODS

Study location

The study is located on the Kisatchie National Forest in central LA. Two replications are at latitude 31° 6'N, longitude 92° 36'W on a Ruston fine sandy loam (fine-loamy, siliceous, semiactive, thermic Thermic Paleudults) containing some Malbis fine sandy loam (fine-loamy, siliceous, subactive, thermic Plinthic Paleudults) and Gore very fine sandy loam (fine, mixed, active, thermic Vertic Paleudualfs) (site 1). Three replications are at latitude 31° 1'N, longitude 92° 37'W on a Beauregard silt loam (fine-silty, siliceous, superactive, thermic Plinthaquic Plaeudults) and Malbis fine sandy loam complex (site 2). A mixed pine-hardwood forest originally occupied both sites. Site 1 was clearcut harvested in 1996 and roller-drum chopped and burned in August 1997. Site 2 was clearcut harvested, sheared, and windrowed in 1991 and burned in 1993 and 1996. Vegetation at both sites included *Schizachyrium*, *Panicum*, and *Dichanthelium* grass species that are native to western longleaf pine ecosystems (Peet 2006). Grass cover was less at site 2 than at site 1 due to the prevalence of herbaceous plants such as swamp sunflower (*Helianthus angustifolius* L.), and woody shrubs such as wax myrtle (*Morella cerifera* (L.) Small).

We established treatment plots (22 by 22 m; 0.048 ha) at each location and delineated blocks by soil drainage and topography. Three vegetation management treatments were established: (1) Control (C)—no management activities after planting, (2) Prescribed burning (B)—plots were burned using the strip headfire method in spring, and (3) Herbicides (H)—herbicides were applied after planting for herbaceous and arborescent plant control. Specifically, the H plots at site 1 were rotary tilled in December 1996. In May 1997 and April 1998, sethoxydim for grass control and hexazinone for herbaceous plant control, in aqueous solution, were applied in 0.9-m-wide bands centered over the rows of unshielded seedlings. The rate of sethoxydim application was 0.37 kg active ingredient (ai)/ha, and for hexazinone the rate was 1.12 kg ai/ha. At site 2, no tillage was necessary and only

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hexazinone was banded in April 1998 and 1999 because the sparse occurrence of grasses did not warrant the use of sethoxydim. In April 1998 and May 1999 at both sites, triclopyr at 0.0048 kg acid equivalent/liter was tank mixed with surfactant and water and applied as a directed foliar spray to competing arborescent vegetation. Recovering brush was cut by hand in February 2001. Container-grown longleaf pine seedlings from genetically improved Louisiana (site 1) and Mississippi (site 2) seed sources were planted at a spacing of 1.8 by 1.8 m in November 1997 and March 1997, respectively. Treatment plots contained 12 rows of 12 seedlings and measurement plots were the internal 8 rows of 8 seedlings in each treatment plot. Site 2 was prescribed burned in May 1998 and both sites were prescribed burned in June 2000, and May 2003 and 2005. One month after prescribed fires in 2003 and 2005, our visual evaluation of sapling crowns indicated that 80 percent or more of the foliage was scorched.

Measurements

In late September through early October of 2003, 2004, and 2005, we chose three saplings per plot from the outer two rows of each treatment plot and flagged them. Saplings were randomly chosen from each of three 1/3 percentiles of sapling total tree height per plot. In 2003 and 2004, the flagged saplings were used for destructive sampling of both aboveground biomass and root biomass. In 2005, the flagged saplings were used for determination of root biomass.

The groundline diameter and total height of all saplings in each measurement plot were quantified in winter 2003, 2004, and 2005. We measured groundline diameter and total height of the flagged saplings destructively sampled in 2003 and 2004, and determined total aboveground dry weight after foliage, branches, and stems had been dried to equilibrium at 70 °C. Regression equations to predict total aboveground dry weight as a function of groundline diameter and total height were constructed as described by Sword Sayer and others (2006). With the measurement plot growth data, these equations were used to predict the total aboveground biomass of all saplings in the measurement plots in 2003, 2004, and 2005. Aboveground biomass (AGB) was expressed as megagrams (Mg) per hectare (ha).

Three soil cores (6.5 cm diameter) were extracted 0.5 m from the base of the stem of each flagged sapling using a metal coring device (Veihmeyer 1929). Core locations were random around the circumference of the sapling. Cores were partitioned into 0- to 20-cm and 20- to 30-cm soil depth increments, pooled by depth increment and sapling, and refrigerated until processing. Root biomass was removed from soil samples by wet sieving (1-mm^2 mesh). Pine roots were distinguished from non-pine roots based on diameter, color, plasticity, and the appearance of lateral roots and ectomycorrhizae. Using digital calipers, pine roots were separated by diameter into three categories: (1) very fine plus fine, (2) small, and (3) medium and larger (Sutton and Tinus 1983). Very fine plus fine roots were 0- to 2-mm diameter, and small roots were >2- to 5-mm diameter at the midpoint of the main lateral root. Medium and larger roots were >5 mm diameter. Categories of pine roots were further separated into live and dead categories based on color, plasticity, the appearance of lateral roots and ectomycorrhizae, and adherence of the cortex to the vascular cylinder. Very fine plus fine and small pine roots were oven-dried (70 °C) to equilibrium, ground in a Wiley mill (1-mm^2 mesh), and combusted (450 °C, 8 h) to obtain ash-free dry weights. Very fine plus fine and small pine ash-free root biomass, medium and larger pine root biomass, and non-pine root biomass at the 0- to 20-cm and 20- to 30-cm soil depths were expressed as milligrams (mg) of root tissue per cubic centimeter (cm^3) of soil volume. Data were summed to obtain values of very fine plus fine pine root biomass that was live or dead (LiDeFi), and very fine plus fine and small pine root biomass that was live (LiFiSm), dead (DeFiSm), and live or dead (LiDeFiSm).

Statistical Analysis

Root biomass categories were transformed to square root or natural logarithm (ln) values to establish normality, and evaluated by analyses of variance using a split plot in space, randomized complete block design with five blocks (SAS 2000). Depth was the whole plot effect and vegetation management was the subplot effect. Effects were considered significant at $P \leq 0.05$ unless otherwise noted. Means were compared by the Tukey test and considered significantly different at $P \leq 0.05$ unless otherwise noted.

Plot AGB was transformed to ln values and non-pine root biomass, LiDeFi pine root biomass, and LiDeFiSm pine root biomass were transformed to square root values to establish normality. With ln (AGB) as the covariate, transformed values of non-pine root biomass, and LiDeFi and LiDeFiSm pine root biomass at the 0- to 20-cm and 20- to 30-cm soil depths were evaluated by analyses of covariance using a randomized complete block split plot in time design with five blocks (SAS 2000). Year was the whole plot effect and vegetation management was the subplot effect. Effects were considered significant at $P \leq 0.05$ unless otherwise noted. Means were compared by the Tukey test and considered significantly different at $P \leq 0.05$ unless otherwise noted.

RESULTS

The variation associated with pine root biomass in the >2- to 5- and > 5-mm diameter categories precluded several root biomass variables and their transformed values from being normally distributed. After square root or ln transformations, seven root biomass variables were normally distributed. Analyses of variance and covariance were conducted for the following root biomass variables: non-pine root biomass, and LiFi, DeFi, LiDeFi, LiFiSm, DeFiSm, and LiDeFiSm pine root biomass.

Root biomass variables were significantly affected by depth (table 1). Averaged across all years, non-pine and pine root biomass in the 20- to 30-cm soil depth were approximately 29 and 35 percent of that in the 0- to 20-cm soil depth, respectively. In 2003, 2004, and 2005, non-pine root biomass was significantly affected by vegetation management treatment with less on the H plots compared to the C and B plots (fig. 1A). In 2003 and 2004, pine root biomass was significantly affected by vegetation management treatment. Values of LiFiSm and LiDeFiSm pine root biomass were greater on the H plots compared to the C and B plots (fig. 1C). In 2004, LiFi, DeFi, and LiDeFi pine root biomass were

Table 1—Probabilities of a greater *F*-value for the non-pine and pine root biomass of restored longleaf pine saplings in central Louisiana for three consecutive years in response to three vegetation management treatments

		Root biomass category						
Source of variation	df[a]	Non-pine	Live, pine, 0-2 mm diameter	Dead pine, 0-2 mm diameter	Live+dead, pine, 0-2 mm diameter	Live, pine, 0-5 mm diameter	Dead, pine, 0-5 mm diameter	Live+dead, pine, 0-5 mm diameter
				2003				
Block (B)[b]	4	0.2577	NS[d]	NS	NS	0.3301	NS	0.4227
Depth (D)	1	0.0206				0.0568		0.0452
B x D	4	0.4434				0.0699		0.1794
Treatment (T)[c]	2	0.0145				0.0020		0.0045
T x D	2	0.9176				0.2771		0.6117
				2004				
B	4	0.2732	0.1806	0.7376	0.3068	0.3391	NS	0.3345
D	1	0.0001	0.0010	0.0025	0.0009	0.0026		0.0033
B x D	4	0.2012	0.5861	0.7587	0.5004	0.4694		0.3347
T	2	0.0002	0.0013	0.0015	0.0003	0.0044		0.0006
T x D	2	0.0018	0.3935	0.7355	0.5625	0.9744		0.0728
				2005				
B	4	0.1402	0.3238	0.2154	0.1022	0.9521	0.3338	0.8999
D	1	0.0026	0.0005	0.0008	0.0001	0.0026	0.0006	0.0018
B x D	4	0.6895	0.7977	0.6277	0.9420	0.4834	0.7907	0.4122
T	2	0.0727	0.3678	0.2813	0.3053	0.1330	0.2621	0.1147
T x D	2	0.8623	0.1779	0.2186	0.1953	0.1344	0.3896	0.1305

[a] df: degrees of freedom
[b] Analyses were conducted with data transformed to their square root or natural logarithm values.
[c] Treatments were no vegetation management (C), vegetation management by repeated prescribed fire (B), and vegetation management by herbicide application (H).
[d] NS: Not statistically significant

greater on the H plots compared to the C and B plots (fig. 1B), and DeFiSm pine root biomass was greater on the H plots compared to the C plots (fig. 1C). In 2005, LiDeFi and LiDeFiSm pine root biomass exhibited non-significant trends similar to those found in 2003 and 2004.

Non-pine root biomass at the 0- to 20-cm soil depth and LiDeFi pine root biomass at the 20- to 30-cm soil depth, adjusted by ln (AGB), were significantly affected by year (table 2). Adjusted non-pine root biomass at the 0- to 20-cm soil depth in 2004 and 2005 (4.09 ± 0.02 mg/cm^3) was more than twice that in 2003 (2.02 ± 0.03 mg/cm^3), and adjusted LiDeFi pine root biomass at the 20- to 30-cm soil depth in 2004 (0.056 ± 0.002 mg/cm^3) was 69 percent less than that in 2003 (0.182 ± 0.002 mg/cm^3). Although year had a marginally significant effect on LiDeFi pine root biomass at the 0- to 20-cm soil depth (P = 0.0590), means were not significantly different by the Tukey test.

Non-pine root biomass at the 0- to 20-cm soil depth and LiDeFiSm pine root biomass at the 20- to 30-cm soil depth, adjusted by ln (AGB), were significantly affected by vegetation management treatment (table 2), but means were not significantly different by the Tukey test. Vegetation management treatment had a marginally significant effect on adjusted LiDeFi pine root biomass at the 20- to 30-cm depth (P = 0.0643). Adjusted LiDeFi pine root biomass at the 20- to 30-cm soil depth was 47 percent less on the B plots (0.078 ± 0.001 mg/cm^3) compared to the C plots (0.149 ± 0.002 mg/cm^3) (fig. 2B).

DISCUSSION

Average pine very fine plus fine root biomass (≤ 2 mm diameter) in the 0- to 30-cm soil depth across management treatments and years was 0.3 mg/cm^3 or 30 kg/ha. In comparison to longleaf pine root biomass observations elsewhere, this value is low. For example, depending on age and management activity, longleaf pine stands on sandy soils in southwestern Georgia had 400 to 1 000 kg/ha of pine root

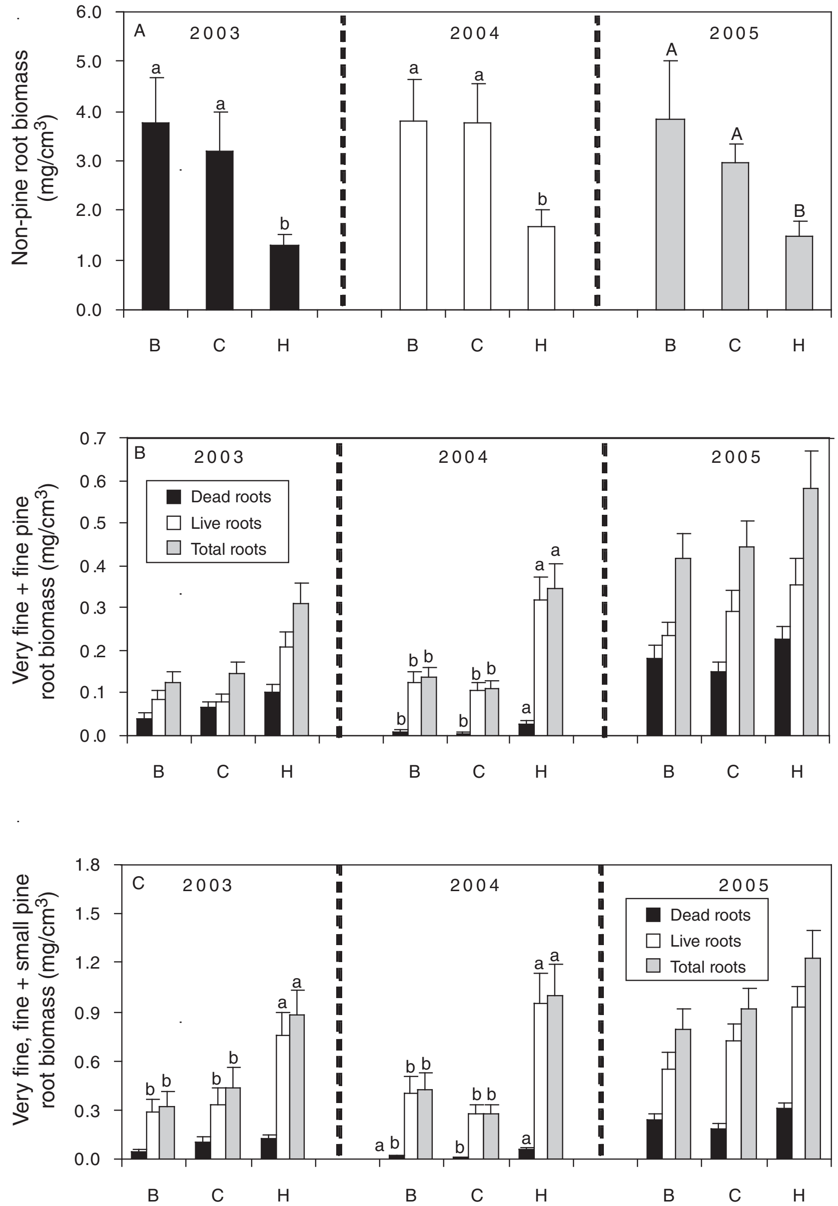

Figure 1—Non-pine root biomass (A), pine root biomass that was 0- to 2-mm diameter (B), and pine root biomass that was 0- to 5-mm diameter in 2003 , 2004, and 2005 in response to no vegetation management (C), vegetation management with repeated prescribed fire (B), and vegetation management by herbicide application (H). Bars represent one standard error of the mean. Means within a year and root biomass category associated with a different lower, or upper case letter are significantly different at $P \leq 0.05$ or $P \leq 0.10$, respectively, by the Tukey test.

biomass ≤ 2 mm in diameter in the 0- to 30-cm soil depth (Carter and others 2004, Jones and others 2003). On sandy soils in north central Florida, Brockway and Outcalt (1998) reported a range of pine root biomass ≤ 5 mm in diameter plus non-pine fine root biomass in the 0- to 20-cm soil depth between 500 and 4 000 kg/ha, depending on distance from the gap edge of mature longleaf pine. In a 65 year old longleaf pine stand on a silty soil in central LA, Sword and Haywood (1999) reported a value of approximately 3 g/dm^3 or 3 000 kg/ha at the 0- to 20-cm soil depth for pine root biomass ≤ 2 mm in diameter. The wide range of fine root biomass values observed for longleaf pine may be attributed to stand age and variability. At our study site, we expect longleaf pine fine root biomass and the uniformity of its distribution to increase as saplings grow into trees and crown closure approaches (Kozlowski and others 1991, Vogt and Persson 1991). The influence of soil resource availability on carbon allocation to fine root production may have also affected longleaf pine root biomass—with more root biomass produced per unit of leaf area on the xeric sites of Georgia and Florida, compared to our mesic study site (Addington and others 2005). Finally, we extracted soil cores for root biomass in late September through early October. At the same time in central Louisiana, longleaf pine root biomass in the surface soil may have been low due to the influence of seasonal drought on fine

Table 2— Probabilities of a greater F-value associated with the analyses of covariance of non-pine root biomass, sapling longleaf pine very fine and fine root biomass that was live or dead (L+D/0-2), and sapling longleaf pine very fine, fine, and small root biomass that was live or dead (L+D/0-5). Data were collected at two depths and in three consecutive years in central Louisiana in response to three vegetation management treatments.

Source of variation	df[a]	Depth	Root biomass variable		
			Non-pine	L+D/0-2	L+D/0-5
Covariate[b]	1	0-20 cm	0.1137	0.0040	0.0053
Block (B)[c]	4		0.8351	0.4691	0.5843
Year (Y)	2		0.0369	0.0590	0.6803
B x Y	8		0.1266	0.8265	0.0457
Treatment (T)[d]	2		0.0259	0.2520	0.3834
Y x T	4		0.9151	0.5689	0.1496
Covariate	1	20-30 cm	0.8114	0.0058	0.0262
Block (B)	4		0.4764	0.8377	0.4943
Year (Y)	2		0.1110	0.0139	0.1633
B x Y	8		0.2160	0.3702	0.2447
Treatment (T)	2		0.6770	0.0643	0.0451
Y x T	4		0.8076	0.1529	0.0959

[a] df: degrees of freedom
[b] The covariate was the natural logarithm of plot aboveground biomass (Mg/ha).
[c] Analyses were conducted with data transformed to their square root or natural logarithm values.
[d] Treatments were no vegetation management (C), vegetation management by repeated prescribed fire (B), and vegetation management by herbicide application (H).

root survival and growth (Marshall 1986, Sword Sayer and Haywood 2006).

The year-to-year variation that we observed in adjusted non-pine root biomass at the 0- to 20-cm soil depth and adjusted pine root biomass at the 20- to 30-cm soil depth suggests that root processes were responsive to environmental and/or physiological factors that differed among years. An obvious factor that may have controlled root activity is climate. Precipitation was greater in 2004 (196 cm) than in 2003 (117 cm) and 2005 (109 cm) (SRCC 2007). Further, precipitation between March and August of 2004 was 47 percent greater than normal, while precipitation between March and August of 2003 and 2005 was 34 and 50 percent below normal, respectively. The positive non-pine root biomass response at the 0- to 20-cm soil depth associated with elevated rainfall in 2004 and maintenance of this belowground biomass in 2005 demonstrate one mode by which understory vegetation may have capitalized on an opportunity to further its establishment belowground (Jones and others 2003). Because year did not significantly affect pine root biomass at the 0- to 20-cm soil depth, however, our data present no evidence that soil resource exploitation by non-pine roots affected pine root biomass.

Elevated precipitation in 2004 also could have been responsible for reduced values of adjusted LiDeFi pine root biomass at the 20- to 30-cm soil depth in 2004 compared to 2003. The peak period of pine root production in central Louisiana generally begins in April and continues through July (Sword Sayer and Haywood 2006, Sword Sayer and Tang 2004). Monthly rainfall in May and June of 2004 was 13 and 15 cm, respectively, which is greater than twice the normal rainfall (SRCC 2007). During the early portion of the peak period of root growth, soil in the 20- to 30-cm soil depth may have been saturated due to the presence of a perched water table and the inherently low hydraulic conductivity of this silty soil (Kerr and others 1980). New pine root growth in 2004 may have been restricted to the 0- to 20-cm soil depth until adequate transpiration and soil water loss created a more aerobic soil environment at the 20- to 30-cm soil depth. By 2005, residual effects of this soil saturation theory were absent with similar adjusted LiDeFi pine root biomass in 2003 and 2005 at the 20- to 30-cm soil depth.

Carter and others (2004) observed a reduction in longleaf pine fine root biomass at the 0- to 30-cm soil depth over a 7 month period after the loss of approximately 95 percent of the foliage by artificial crown scorch in June. Similarly, we found that 80 to 100 percent crown scorch was associated with lower adjusted LiDeFi pine root biomass at the 20- to 30-cm

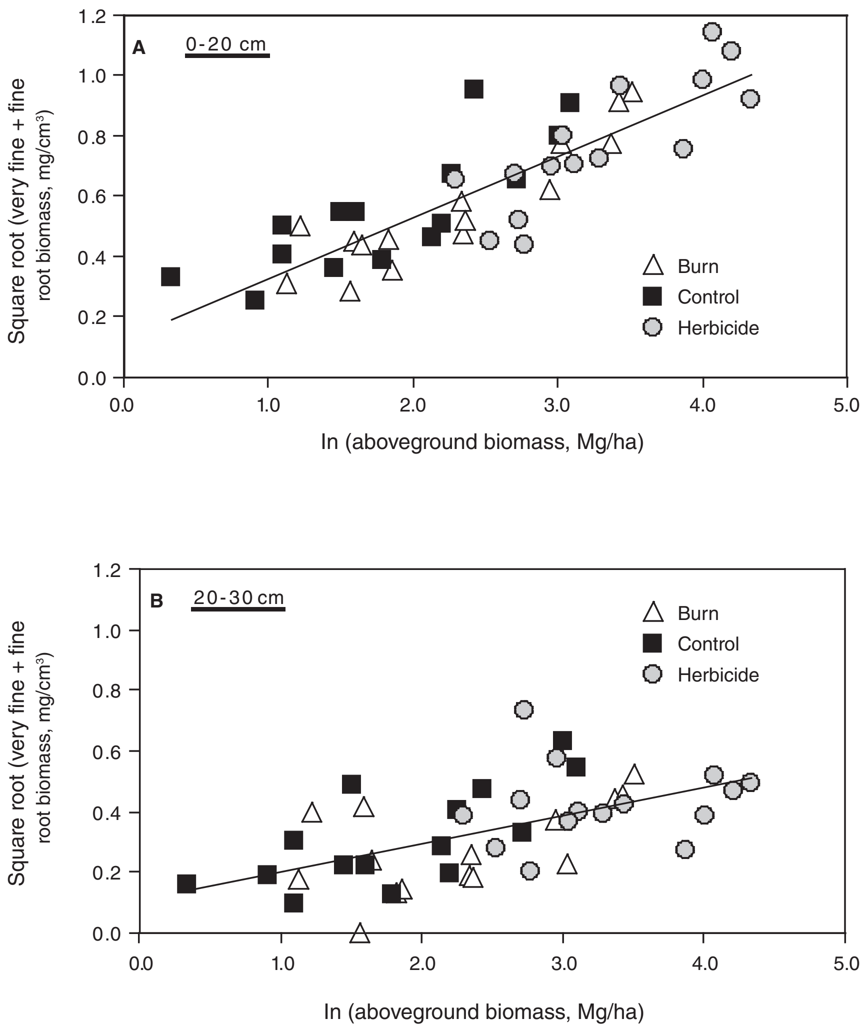

Figure 2—Relationship between the natural logarithm of predicted aboveground biomass and the square root of pine root biomass that was 0- to 2-mm diameter at the 0- to 20-cm depth (A), and the 20- to 30-cm depth (B), in response to no vegetation management (Control), vegetation management with repeated prescribed fire (Burn), and vegetation management by herbicide application (Herbicide). Data are plot means in 2003, 2004, and 2005.

soil depth. We did not, however, observe a similar response at the 0- to 20-cm soil depth. Dissimilar pine root biomass responses to prescribed fire at different soil depths may be attributed to the rate at which root growth recovered during the several month period after prescribed fire in May. With the reestablishment of foliage after fire, carbon allocation to and within root systems controlled root production. We found an average of 69 percent more fine root biomass in the 0- to 20-cm soil depth compared to the 20- to 30-cm soil depth, suggesting that the metabolic activity and, therefore, sink strength in the 0- to 20-cm soil depth was greater than that in the 20- to 30-cm soil depth. Greater sink strength in the 0- to 20-cm soil depth compared to the 20- to 30-cm soil depth may have benefited recovery of fine root biomass in the 0- to 20-cm soil depth, so that several months later fine root biomass was not different between the B and C plots at this depth. In contrast, less fine root biomass at the 20- to 30-cm depth on the B plots—compared to the C plots—may have been a function of both a limited carbohydrate supply for root metabolism and low sink strength.

Our results provide insight regarding improvements to our experimental methodology. Because we observed a reduction in fine root biomass only at the 20- to 30-cm depth, and this may be attributable to variation in root system sink strength and future root biomass observations after crown scorch, we will conduct future observations at a higher resolution. Frequent observations that start immediately after prescribed fire, rather than one observation made several months after prescribed fire, will improve our ability to discern root biomass responses throughout the period of foliage reestablishment and as the seasonal change in sink strength of different parts of the root system. Further, it appears that evaluation of longleaf pine roots larger than 2 mm diameter at our study sites requires a larger sample size (i.e., n = 3). Because the time required to process longleaf pine root biomass collected by soil coring precludes an increase in sample size, future research will employ a different sampling method. Finally, the potential influence of climate on non-pine and pine root biomass in our study suggests that key climate and soil measurements should accompany future longleaf pine root biomass observations. With this information, longleaf pine root biomass could be evaluated as a function of environmental stimuli; the resolution of treatments effects could then be improved.

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