Soil Physical Property Response to Prescribed Fire in Two Young Longleaf Pine Stands on the Western Gulf Coastal Plain

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Abstract—*Prescribed fire every 2 to 4 years is an important component of longleaf pine ecosystem restoration. Under some circumstances, repeated fire could change soil physical properties on the Western Gulf Coastal Plain. The objective of this study was to evaluate the soil bulk density, porosity fractions, and plant-available water holding capacity of restored longleaf pine on the Western Gulf Coastal Plain in response to two vegetation management alternatives that included the application of three prescribed fires over a 6-year period. Soil microporosity and plant-available water holding capacity were influenced by both vegetation management alternatives indicating that a reduction in the perturbation of soil by roots may be a mechanism of soil physical property change. Apparent soil texture effects on plant-available water holding capacity suggest that further research is needed to determine if repeated prescribed fire exacerbates the naturally low plant-available water holding capacity of some soils on the Western Gulf Coastal Plain.*

Introduction

In the late 1800s, longleaf pine (*Pinus palustris* P. Mill.) ecosystems occurred across 37 million ha of the Southeastern United States; today, less than 2 million ha of these forests remain (Landers and others 1995; Outcalt 2000; Outcalt and Sheffield 1996). This decrease in range is attributed to extensive logging followed by unsuccessful reestablishment due to regeneration problems 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 often depend on, the occurrence of fire every 2 to 4 years (Brockway and Lewis 1997; Haywood and others 2001; Landers and others 1995; Outcalt 2000), successful longleaf pine ecosystem restoration is dependent on prescribed fire. Now that fire has been reconsidered as a forest management tool in the South (Brockway and Lewis 1997; Brockway and Outcalt 2000; Gilliam and Platt 1999; Haywood and others 2001), and research has identified successful approaches to regenerate longleaf pine (Barnett and McGilvray 1997; Boyer 1989; McGuire and others 2001; Ramsey and others 2003; Rodríguez-Trejo and others 2003), restoration of this species to portions of its natural range is being realized.

Soil quality will be sustained over a long-term period of repeated prescribed fire if the role of vegetation in controlling soil chemical and physical properties continues. Under some circumstances, however, repeated crown scorch and eradication of understory vegetation may negatively affect various soil physical properties that impact the bulk density and plant-available water holding capacity of Western Gulf Coastal Plain soils. For example, if postfire plant physiological processes are unable to supply the energy needed to maintain

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active root growth, both the perturbation of soil by roots and the deposition of organic matter in the soil will suffer. Without adequate perturbation and organic matter, soil bulk density and strength increase (Fisher and Binkley 2000). Where inherent soil physical properties approach root-growth limiting conditions, root system expansion may be dependent on conduits provided by old root channels (van Lear and others 2000). If carbon allocation to root growth is inhibited, the network of old root channels and the potential for soil resource acquisition will be restricted. The soils of longleaf pine forests on the Western Gulf Coastal Plain are characterized as silty and clayey (Peet 2006), with the potential for naturally low subsoil porosity and high bulk density (Patterson and others 2004; Pritchett 1979). Where inherent soil physical property values approach root growth limitations, fire-induced changes could lead to an unnecessary loss of soil quality.

The objective of this study was to evaluate the soil physical properties of restored longleaf pine on the Western Gulf Coastal Plain in response to two vegetation management alternatives that included the application of prescribed fire in spring of 2000, 2003, and 2005. It is hypothesized that repeated fire reduced soil quality by decreasing porosity and plant-available water holding capacity, and by increasing bulk density.

Materials and Methods

Study Location

The study, on the Kisatchie National Forest in central Louisiana, included two replications at latitude 31º 6'N, longitude 92º 36'W on a Ruston fine sandy loam (fine-loamy, siliceous, semiactive, thermic Thermic Paleudults) with some Malbis fine sandy loam (fine-loamy, siliceous, subactive, thermic Plinthic Paleudults) and Gore very fine sandy loam (fine, mixed, active, thermic Vertic Paleudualfs) with a slope of 1 to 5 percent (site 1). Three replications were at latitude 31° 1'N, longitude 92º 37'W on a gently sloping (1 to 3 percent) 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 prescribe 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 compared to 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.

At each location, treatment plots (22 x 22 m; 0.048 ha) were established and blocks were delineated 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.
3. Herbicides (H)—herbicides were applied after planting and before age 3 years for herbaceous and arborescent plant control, and recovering brush was cut by hand in 2001 (Sword Sayer and others 2006).

Site 2 was burned in May 1998 and both sites were burned in June 2000, and May 2003 and 2005. Container-grown longleaf pine seedlings from a genetically improved Louisiana seed source (site 1) and Mississippi seed source (site 2) were planted at a spacing of 1.8 x 1.8 m in November 1997 and March 1997, respectively. Treatment plots contained 12 rows of 12 seedlings. Measurement plots contained the internal eight rows of seedlings in each treatment plot.

Measurements

In fall 2002, three saplings of average height per measurement plot were randomly identified. In fall 2004 and spring 2006, a tractor-mounted hydraulic probe was used to extract one long (5.1 cm diameter x 61 cm long) and one short (5.1 cm diameter x 30.5 cm long) soil core 1 m from the base of each selected sapling. Cores were placed in capped plastic liners and refrigerated until processing. Intact soil core increments were excised from the A, Bt1, and Bt2 horizons of long soil cores, and the A horizon of short soil cores. During long soil core processing, the depth to the argillic horizon (Bt1) was visually estimated by color and texture. Specifically, immediately below the darkly colored A horizon, a metal blade was pulled along the core length. The upper Bt horizon was identified as the depth where there were distinct changes in resistance to the blade and the appearance of the blade tracing. The Bt1 core increment was defined as 2 to 12 cm below this depth. Two 1 cm deep core sections each from the A horizon core increment (2 to 12 cm), the Bt1 horizon core increment, and the Bt2 horizon core increment (50 to 60 cm) were excised using a band-saw. Similarly, short soil cores were processed so that two intact 1 cm core sections were excised from the A horizon core increment. In each year, 90 soil cores were processed for A horizon information, and 45 soil cores were processed for Bt1 and Bt2 horizon information.

From the long and short soil cores, two core sections from each soil horizon were placed in plastic rings. One set of rings was positioned on either an equilibrated -0.1 MPa or –1.5 MPa ceramic pressure plate. Bulk density, total porosity fraction, microporosity fraction, macroporosity fraction, and plant-available soil water holding capacity were determined with data generated by the water retention method (Klute 1986) and the core bulk density method (Blake and Hartge 1986). Bulk density (BD) was expressed as core section dry weight (g) divided by core section volume (cm^{-3}). Total porosity (TOP) was calculated by equation 1.

$$\text{TOP} = 1-[\text{BD (g cm}^{-3})/\text{particle density (2.65 g cm}^{-3})] \quad (1)$$

Microporosity (MIP) was calculated by equation 2 where WATFC is the soil water content of the core section at –0.03 MPa, CSV is the core section volume and SGW is the specific gravity of water.

$$\text{MIP} = [\text{WATFC (g)/CSV (cm}^{3})]/\text{SGW (1 g cm}^{-3})] \quad (2)$$

Macroporosity (MAP) was determined by subtracting MIP from TOP. Percent plant-available soil water holding capacity (PAWHC) was calculated by equation 3 where WATFC and WATWP are the soil water content of core sections at –0.03 MPa and –1.5 MPa, respectively.

$$\text{PAWHC} = \frac{\left[(\text{WATFC (g)/CSV (cm}^{3}))-(\text{WATWP (g)/CSV(cm}^{3}))\right]}{\text{SGW (1 g cm}^{-3})} \text{x } 100 \quad (3)$$

Statistical Analysis

Values of BD, TOP, MIP, MAP, and PAWHC for each horizon were transformed, as needed, to natural logarithm or square root values to establish normality, and evaluated by analysis of variance using a split plot in time, randomized complete block design with five blocks. Year was the whole plot effect and vegetation management treatment was the subplot effect. Effects were considered significant at $P \leq 0.05$. Means were compared by the Tukey test and considered significantly different at $P \leq 0.05$.

Results and Discussion

All soil physical properties except PAWHC were significantly affected by year in at least two soil horizons (table 1). Values of bulk density in the A, Bt1, and Bt2 horizons were, respectively, 5, 8, and 8 percent lower in 2006 compared to 2004 (table 2). Value of TOP and MAP were greater and values

Table 1—Probabilities of a greater *F*-value for soil physical properties of restored longleaf pine in central Louisiana in response to three vegetation management treatments.

Effect	df[a]	A Horizon	Bt1 Horizon	Bt2 Horizon
Bulk density(BD)[b]				
Block (B)	4	0.0351	0.2296	0.0690
Year (Y)	1	0.0250	0.0172	0.0056
B x Y	4	0.3364	0.1514	0.5146
Treatment (T)	2	0.2789	0.4019	0.7547
T x Y	2	0.5698	0.3928	0.7447
Total porosity (TOP)				
B	4	0.0351	0.2296	0.0801
Y	1	0.0250	0.0172	0.0066
B x Y	4	0.3364	0.1514	0.4829
T	2	0.2789	0.4019	0.7419
T x Y	2	0.5698	0.3928	0.7619
Microporosity (MIP)				
B	4	0.0025	0.0613	0.5435
Y	1	0.1688	0.0455	0.0187
B x Y	4	0.8664	0.1618	0.1960
T	2	0.0047	0.0741	0.0184
T x Y	2	0.7568	0.2509	0.7785
Macroporosity (MAP)				
B	4	0.0167	0.1120	0.1374
Y	1	0.0298	0.0163	0.0039
B x Y	4	0.5552	0.1048	0.1086
T	2	0.0309	0.8419	0.2650
T x Y	2	0.8553	0.4261	0.5020
Plant-available water holding capacity (PAWHC)				
B	4	0.0057	0.0209	0.1167
Y	1	0.5735	0.9603	0.8585
B x Y	4	0.7954	0.0667	0.4637
T	2	0.0063	0.2323	0.5001
T x Y	2	0.6581	0.4449	0.5909

[a] degrees of freedom
[b] A horizon MIP, and A and Bt1 horizon PAWHC were transformed to square root values; BD was transformed to its natural logarithm.

Table 2—Means and standard errors of soil physical property values of restored longleaf pine over a 3-year period in central Louisiana averaged across three vegetation management treatments and two locations. Within a variable and soil horizon, means associated with different letters are significantly different at $P \leq 0.05$ by the Tukey test.

Year	Variable			
	BD[a]	TOP	MIP	MAP
A horizon				
2004	1.44 ± 0.03 a	0.46 ± 0.01 b	0.26 ± 0.01	0.19 ± 0.02 b
2006	1.37 ± 0.01 b	0.48 ± 0.01 a	0.25 ± 0.01	0.23 ± 0.01 a
Bt1 horizon				
2004	1.61 ± 0.03 a	0.39 ± 0.01 b	0.33 ± 0.01 a	0.07 ± 0.01 b
2006	1.48 ± 0.01 b	0.44 ± 0.01 a	0.30 ± 0.01 b	0 14 ± 0.01 a
Bt2 horizon				
2004	1.67 ± 0.03 a	0.37 ± 0.01 b	0.33 ± 0.01 a	0.05 ± 0.01 b
2006	1.54 ± 0.01 b	0.42 ± 0.01 a	0.30 ± 0.01 b	0.12 ± 0.01 a

[a] BD: Bulk density (g/cm^3); TOP: total porosity fraction; MIP: microporosity fraction; MAP: macroporosity fraction.

of MIP were lower in 2006 compared to 2004. The magnitude of these differences increased with soil horizon depth. It is speculated that these effects were caused by soil water content at the time of soil core collection. In 2004, soil cores were collected in fall when the soil was dry; in 2006, soil cores were collected in spring when the soil was wet. The Ultisol soils in this study are characterized by a suite of clay minerals dominated by kaolinite, which exhibits no shrink-swell potential (Buol and others 1980; Kerr and others 1980). However, some soil core expansion was possible after removal from the soil profile due to the influence of organic matter and minor clay minerals such as vermiculite on expansion (Buol and others 1980; Foth 1978). The clay fraction of the soil series in this study increases with soil horizon depth (Kerr and others 1980; Soil Survey Staff 2007). The effect of this clay fraction on soil core expansion may have increased with depth causing annual differences in bulk density, TOP, MAP, and MIP to also increase with depth.

With one exception, all significant effects of vegetation management treatment on soil physical properties were found in the A horizon (table 1). Specifically, MAP, MIP, and PAWHC in the A horizon, and MIP in the Bt2 horizon were influenced by vegetation management treatment. Values of MAP were 25 percent greater on the B plots, and values of MIP were 15 and 18 percent lower, respectively, on the B and H plots compared to the C plots (fig. 1). Values of PAWHC were 18 percent lower on the B and H plots compared to the C plots. In the Bt2 horizon, MIP was 7 percent lower on the B plots compared to the C plots. Bulk density was not significantly affected by either repeated prescribed fire or chemical vegetation control.

Unwanted vegetation was successfully controlled by repeated prescribed fire and chemical vegetation control during seedling establishment. It is likely that the production and activity of roots associated with this unwanted vegetation were also reduced by B and H treatments. These observations suggest that a reduction in the perturbation of soil by roots is a potential mechanism of soil porosity change in response to B and H.

Noncapillary pore space or MAP is the fraction of soil porosity containing both gravitational water and air space depending on the degree of saturation (Kramer 1983). As the soil drains, MAP provides conduits for aeration. The mortality of woody roots as repeated fire weakens or kills unwanted shrubs and small trees may be linked to greater MAP in the A horizon on

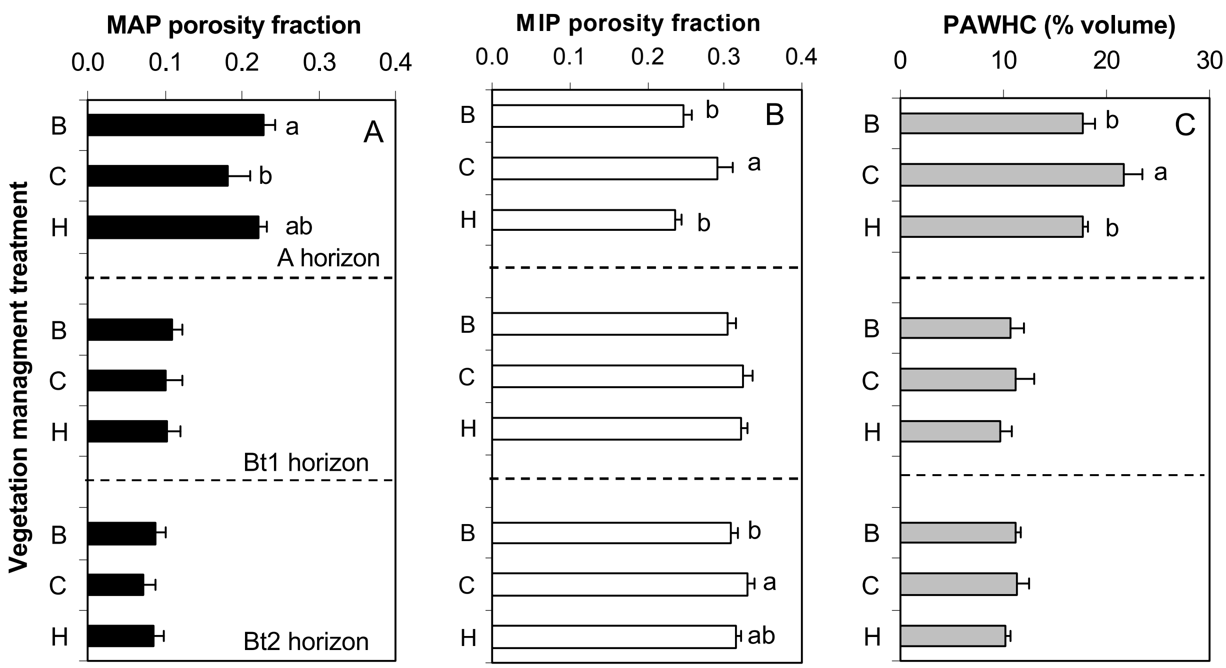

Figure 1—Effects of vegetation management treatment on soil physical properties.

the B plots compared to the C plots. Silty and clayey soils on the Western Gulf Coastal Plain are often poorly drained and remain saturated in winter (Kerr and others 1980). As evapotranspiration increases and these soils dry in spring, perhaps dead root cavities from unwanted shrubs and small trees improve soil aeration on burned sites.

Capillary pore space is the source of water held against gravity at a tension greater than 0.03 MPa. From this, water held at a tension above 1.5 MPa is available for plant uptake (in other words, PAWHC) (Kramer 1983). It is true that unwanted vegetation was successfully controlled by repeated prescribed fire and chemical vegetation control during seedling establishment. However, this was accompanied by 15 to 18 percent reductions in A horizon MIP and PAWHC. Obviously, adequate water is needed to maintain longleaf pine physiology and growth on the Western Gulf Coastal Plain where seasonal drought is common and prolonged drought is possible (Allen and others 1990; Sword Sayer and Haywood 2006). During drought, management-induced reductions in PAWHC have the potential to affect the supply of water to young trees and, therefore, their production. Further research is needed to determine the significance of reduced A horizon PAWHC on the Western Gulf Coastal Plain possibly caused by vegetation control.

Significant block effects were observed for all soil physical property variables in the A horizon, and for PAWHC in the Bt1 horizon (table 1). The separation of some block means suggests that the physical properties at site 1 were distinctly different from those at site 2. The bulk density of the A horizon was variable with a higher value on block 3 compared to most other blocks (fig. 2A). Similarly, MAP was higher on block 4 compared to the other four blocks. It is possible that past management activities such as logging and site preparation introduced variation to the bulk density and MAP of the A horizon.

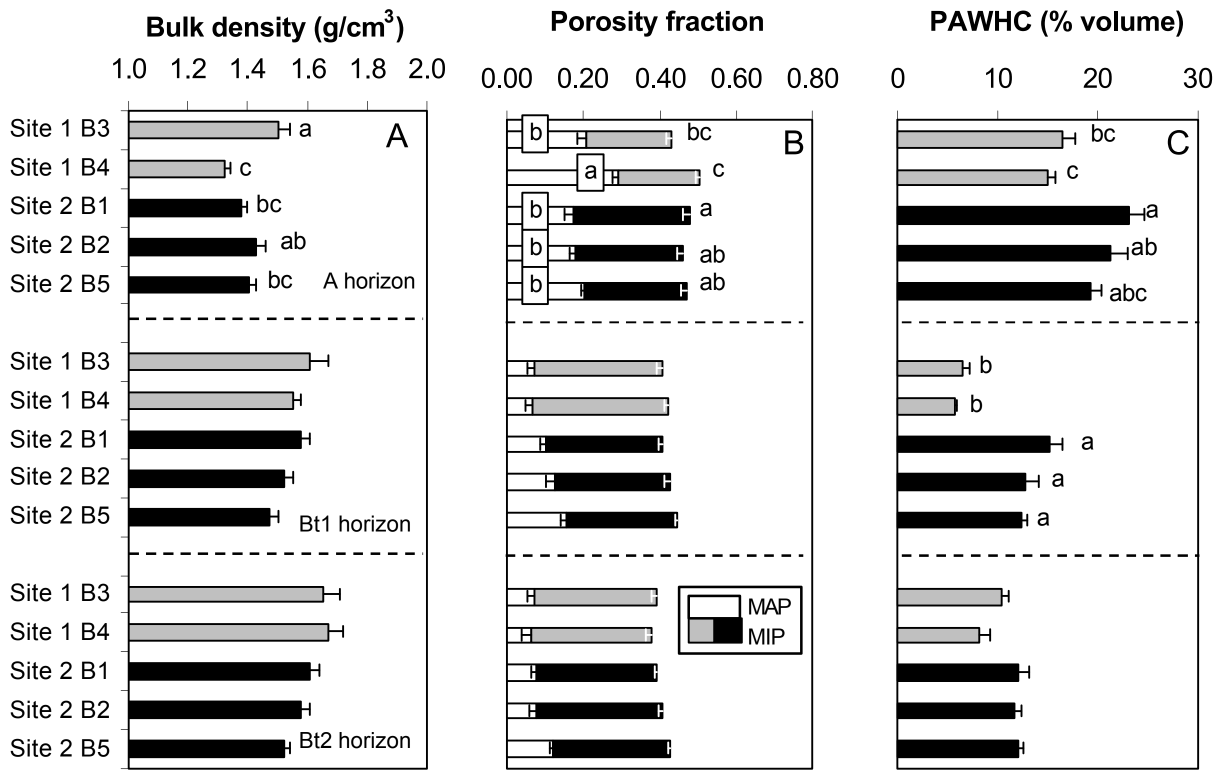

Figure 2—Block effects on the study sites.

For MIP and PAWHC, block means exhibited trends that distinguished site 1 from site 2 (fig. 2B,C). Specifically, A horizon MIP and PAWHC at site 1 were 24 and 26 percent lower, respectively, compared to A horizon MIP and PAWHC at site 2. It is likely that soil texture controlled soil physical property differences at the two sites. Total sand fractions of the A horizon of soils at site 1 and site 2 were similar (Soil Survey Staff 2007). However, the sand fraction of the A horizon of the Ruston soil at site 1 was dominated by fine sand; whereas, that of the A horizon of the Beauregard/Malbis soil at site 2 was dominated by very fine sand (Soil Survey Staff 2007). It is proposed that as sand particle size increased, less MIP contributed to TOP because the larger particle size predisposed porosity to MAP.

Soil texture may have also led to site differences in the Bt1 horizon. The clay fraction of the Bt1 horizon of the Ruston soil at site 1 was greater than that of the Beauregard/Malbis soil at site 2 (Soil Survey Staff 2007). The small particle size of clay enables it to hold more water than sand or silt (Kramer 1983). Small pore sizes associated with clay, however, also result in a large fraction of soil water that is plant-unavailable because it is held at a tension greater than 1.5 MPa. Perhaps greater clay content in the Bt1 horizon resulted in 55 percent less PAWHC at site 1 compared to site 2 (fig. 2C), because the clay fraction of the Ruston soil at site 1 retained more plant-unavailable soil water than the Beauregard/Malbis soil at site 2.

The results of this study suggest that frequent prescribed fire has the potential to affect the soil porosity and plant-available water holding capacity of restored longleaf pine forests on the Western Gulf Coastal Plain. However, soil physical property responses to the application of three prescribed fires over a 6-year period were not severe enough to affect bulk density. Similar trends in MAP, MIP, and PAWHC between the repeated prescribed fire and chemical vegetation control treatments suggest that changes in soil physical properties were associated with altered understory vegetation dynamics. It is hypothesized that vegetation control by prescribed fire or herbicide application reduced soil perturbation by roots, subsequently reducing MIP and PAWHC. Apparent relationships between clay content and soil expansion, and between sand and clay content and PAWHC were noted. Further research is needed to determine if repeated prescribed fire exacerbates the naturally low PAWHC of soils with a higher sand fraction in the A horizon and a higher clay fraction in the Bt1 horizon. This information would help ascertain whether prescribed fire on some Western Gulf Coastal Plain soils influences the supply of water necessary to maintain tree physiological processes.

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