EFFECTS OF VEGETATION MANAGEMENT WITH PRESCRIBED FIRE ON SOIL PHYSICAL PROPERTIES IN A YOUNG LONGLEAF PINE STAND

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Abstract—The intensity and frequency of prescribed fire affects soil properties that control its quality. This project evaluates how six vegetation management treatments, four of which include biennial prescribed fire, affect the soil physical properties in two stands of longleaf pine (*Pinus palustris* Mill.) located on the Kisatchie National Forest, Rapides Parish, LA. The A, Bt1, and Bt2 horizons were evaluated 1 year after the initial prescribed burn. Differences in soil properties between the two stands were apparent in all three horizons. The application of treatments that included the chemical control of woody competition resulted in higher bulk density and lower total porosity of the Bt1 horizon. As long-term biennial prescribed fire continues to remove litter and control woody competition, bulk density and total porosity may respond similarly.

INTRODUCTION

Repeated prescribed fire every 2 to 10 years is essential to perpetuate longleaf pine (*Pinus palustris* Mill.) ecosystems (Outcalt 1997) and is a valuable stand-management tool in the Southeast. The frequency and intensity of prescribed fire affects stand and soil variables that control whole-crown carbon fixation, root system expansion, and therefore, tree growth and water and mineral nutrient uptake. Because pre-fire fuel conditions, in part, control the intensity of prescribed fire, it is of interest to investigate long-term responses of soil properties to vegetation management treatments that affect fuel conditions. This information will help to identify fuel conditions and vegetation management treatments that minimize negative effects of fire on soil properties.

The effects of repeated prescribed fire on forest productivity have generated controversy. Research by Boyer (1987) indicated a reduction in tree growth. However, Waldrop and others (1987) reported inconclusive effects of repeated prescribed fire on tree growth, and Brockway and Lewis (1997) showed no negative effect of routine prescribed fire on southern pine productivity.

Reductions in forest productivity resulting from repeated prescribed fire could be attributed to the effects of crown scorch and leaf area loss on whole-crown carbon fixation and allocation (Johansen and Wade 1987, Sword and Haywood 1999). This could lead to reductions in carbon allocation to root growth and, thus, soil resource uptake. Although frequent prescribed fires usually increase the organic matter content of the surface soil (Lotti 1962, Metz and others 1961, Neary and others 1999), fire-induced reduction in root growth may cause decreases in subsoil organic matter over time. This could result in a decrease in soil water holding capacity and an increase in soil strength and bulk density (Fisher and Binkley 2000).

A second mechanism of reduced forest productivity with repeated prescribed fire is a cumulative loss of soil quality. Again, however, the occurrence of negative effects of fire on soil properties is variable. In mature longleaf pine, Boyer and Miller (1994) found that biennial winter burning reduced soil macropore space and plant-available water, and increased soil bulk density. Moehring and others (1966) found that biennial prescribed burning increased soil bulk density and decreased soil macroporosity, but these responses were apparent only in the upper 5 cm of mineral soil. Minor increases in bulk density were found by Bower (1966) in response to fire, but this effect dissipated within 4 years after treatment. Lotti (1962) and Metz and others (1961) found that the type or frequency of prescribed fire had no detrimental effect on the bulk density or porosity of loblolly pine (*Pinus taeda* L.) forests.

This study is part of a larger research effort to investigate the effects of six vegetation management treatments on prescribed fire intensity and subsequent relationships between fire intensity and longleaf pine growth and physiology, and soil chemical and physical properties. Our present objective is to summarize the effects of vegetation management treatment and soil type on soil bulk density, macroporosity, microporosity, total porosity, and plant-available soil water holding capacity in the A, Bt1, and Bt2 soil horizons after one application of prescribed fire.

MATERIALS AND METHODS

The study is located in two compartments of the Calcasieu Ranger District of the Kisatchie National Forest, Rapides Parish, LA. Soils in one compartment are predominantly Ruston fine sandy loam (fine-loamy, siliceous, thermic, Typic Paleudults) with some Gore silt loam (fine, mixed, thermic, Vertic Paleudalfs) (Kerr and others 1980). Soils in the second compartment are Beauregard silt loam (fine-silty, siliceous, thermic, Plinthaquic Paleudults) and Malbis fine sandy loam (fine-loamy, siliceous, thermic, Plinthic Paleudults).

In 1996, mature mixed pine forests were clear-cut in both compartments. In summer 1997, the study sites were prepared for planting by chopping and burning. In fall 1998, 12 treatment plots (22 by 22 m; 0.048 ha) were established

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in each compartment. In March 1998, container-grown longleaf pine seedlings from one genetically improved, Louisiana seed orchard source were planted at 1.8 by 1.8 m in 12 rows of 12 seedlings each. Measurement plots were the interior eight rows of eight seedlings.

The study is a two-factor experiment with repeated measures in one factor (Neter and others 1990). Six vegetation management treatments are repeated as two blocks in each of the two compartments. Plots in compartments were blocked by apparent permeability, which was assessed by depth to the argillic horizon, texture and the presence of redoximorphic features in the A, E, and Bt1 horizons. The six vegetation management treatments are: (1) control with no vegetation management [C], (2) no burning with chemical control of woody and herbaceous vegetation [NBHW], (3) biennial prescribed burning in June [B], (4) biennial prescribed burning in June plus early chemical control of herbaceous competition [BH], (5) biennial prescribed burning in June plus early chemical control of woody competition [BW], and (6) biennial prescribed burning in June plus early chemical control of herbaceous and woody competition [BHW]. Chemical control of woody vegetation was accomplished by annual application as needed in 1998 and 1999 of Remedy® (triclopyr) to woody competition as a directed foliar spray (4-percent solution). Woody regrowth was hand-felled in 2001. Chemical control of herbaceous vegetation was done as post-plant applications of Velpar® L (hexazinone) (0.4-percent solution) in 0.9-m bands over seedlings in spring of 1998 and 1999. The first prescribed fire was applied to the B, BH, BW, and BHW plots as strip headfires in June 2000.

In fall 2002, three saplings of average height were randomly selected per measurement plot. A tractor-mounted hydraulic probe was used to extract one long soil core (5.1 cm diameter by 61 cm long) and one short soil core (5.1 cm diameter by 30.5 cm long) 1 m from the base of each of the selected saplings. Cores were placed in capped plastic liners and refrigerated until processing. Intact soil core sections were extracted 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 determined, and the Bt1 core increment was defined as 2 to 12 cm below this depth. Two 1-cm-long intact core sections each from the 2 to12 cm core increment, the Bt1 core increment, and the 50 to 60 cm core increment were excised using a band-saw. Similarly, short soil cores were processed so that two intact 1-cm core sections were excised from the 2 to 12 cm core increment.

From the long soil cores, two 1-cm intact core sections from each sapling and soil depth were placed in plastic rings. Rings were positioned either on an equilibrated -0.03 MPa or -1.5 MPa ceramic pressure plate. Similarly, two 1-cm intact core sections from the A horizon of the short soil cores were placed on the equilibrated -0.03 and -1.5 MPa ceramic pressure plates. Bulk density, total porosity fraction, microoporosity 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.

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

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.

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

Macroporosity (MAP) was determined by subtracting MIP from TOP. Finally, 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.

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

For each soil horizon, plot means of soil physical properties were analyzed by analyses of variance for a two-factor experiment with repeated measures in one factor (Neter and others 1990). Overall significance was acknowledged at Pr $\leq$ 0.10. Duncan's Multiple Range test with an α of 0.10 was used to detect significant differences between means.

RESULTS AND DISCUSSION

Soil Bulk Density

Vegetation management treatment significantly affected BD in the Bt1 horizon where BD was greater on the BW, BHW, and NBHW plots than on the control plots (table 1). The BD on the BHW plots was also significantly greater than on the B plots. Values of BD in the A and Bt2 horizons were not significantly affected by vegetation management treatment.

Past research has found a variable response of BD to prescribed fire. For example, no change in BD was detected by Duvall and Linnartz (1967) and Linnartz and others (1966) after two burns in a central Louisiana longleaf pine–bluestem (*Schizachyrium* spp. and *Andropogon* spp.) forest. Moehring and others (1966) found that biennial prescribed fire slightly increased BD in the 0 to 5 cm depth but had no effect on BD in the 5 to 10 cm depth. In contrast, annual prescribed burning of an oak (*Quercus* spp.) forest in Tennessee increased BD in the 0 to 7.6 cm depth compared to no burning and burning every 5 years (Phillips and others 2000). Boyer and Miller (1994) also found that biennial winter burning of longleaf pine stands increased soil BD at the 0 to 5 cm depth. In our study, BD was consistently increased by treatments that chemically reduced woody competition. As woody vegetation was suppressed, root system proliferation and soil perturbation may have been reduced, leading to a reduction in MAP and an increase in BD. Over time, as biennial prescribed fire continues to control woody competition in our study, BD may respond similarly.

Table 1—Mean bulk density, porosity fractions, and PAWHC of the Bt1 horizon at two sapling longleaf pine sites in response to six vegetation management treatments on the Kisatchie National Forest, Rapides Parish, LA

Treatment	Bulk density	Total porosity	Macro-porosity	Micro-porosity	PAWHC
	g cm^{-3}			*percent*	
Control	1.48 c	0.441 a	0.157 a	0.281 a	6.4 a
B	1.54 bc	0.421 ab	0.129 a	0.293 a	5.3 a
NBHW	1.60 ab	0.395 bc	0.088 a	0.308 a	5.6 a
BH	1.58 abc	0.404 abc	0.133 a	0.271 a	7.5 a
BW	1.60 ab	0.401 bc	0.102 a	0.299 a	7.7 a
BHW	1.66 a	0.368 c	0.098 a	0.281 a	9.2 a

PAWHC = plant-available soil water holding capacity; B = biennial prescribed burning in June; NBHW= no burning with chemical control of woody and herbaceous competition; BH = B plus early chemical control of herbaceous competition; BW = B plus early chemical control of woody competition; BHW = B plus early chemical control of herbaceous and woody competition.

Means in a column followed by the same letter are not significantly different at $\alpha = 0.10$.

Porosity Fractions

Past research has shown that reductions in both MAP and MIP occur with repeated prescribed fire (Boyer and Miller 1994, Moehring and others 1966). In our study, MAP and MIP of the A, Bt1, and Bt2 horizons and TOP of the A and Bt2 horizons were not significantly affected by vegetation management treatment. However, TOP of the Bt1 horizon was significantly affected by vegetation management treatment (table 1). Specifically, TOP was lower on the BW, BHW, and NBHW plots than on the control plots, and TOP on the BHW plots was lower than on the B plots. Similar to BD, TOP appears to have responded negatively to the chemical control of woody competition. With long-term repeated prescribed fire and subsequent reductions in competing vegetation, soil porosity may follow the same trend.

Methods used to calculate MAP, MIP, and TOP may have influenced our ability to detect significant treatment effects. In our calculations, TOP was a function of BD; whereas MIP was a function of soil water content at field capacity, and MAP was a function of both BD and MIP. Soil water content at -0.03 MPa is strongly affected by macroporosity and soil structure (Brady and Weil 2002), which are highly variable (Fisher and Binkley 2000). The effect of this variation on soil water content at -0.03 MPa may have been too great to detect significant treatment effects in MAP and MIP.

Plant-Available Soil Water Holding Capacity

Heyward (1939) stated that burning longleaf pine forest soils seldom affected soil moisture holding capacity. However, Boyer and Miller (1994) found that biennial winter burning of longleaf pine stands reduced plant-available water. In our study, vegetation management treatment did not significantly affect PAWHC. This variable was calculated as a function of the difference between soil water content at -0.03 MPa and -1.5 MPa. As with MAP and MIP, the variation associated with soil water content at -0.03 MPa may have been too great to detect significant responses of PAWHC to vegetation management treatment. With a larger soil sample size, research will continue to evaluate the influence of vegetation management treatments on PAWHC and how potential changes in PAWHC affect longleaf pine physiology and growth.

Soil Type

The physical properties of the Ruston-Gore soil type (fine sandy loam-silt loam) and the Beauregard-Malbis soil type (silt loam-fine sandy loam) differed significantly. The BD of the A horizon was similar between soil types, but that of the Bt1 and Bt2 horizons was significantly different (table 2). The BD of the Bt1 and Bt2 horizons on the Ruston-Gore soil were 7.2 and 7.4 percent higher, respectively, than those of the Beauregard-Malbis soil. Values of MAP and MIP in the A, Bt1, and Bt2 horizons were similar between the soil types. Again, variation in MAP and soil structure may have reduced our ability to detect significant differences in MAP and MIP between soil types. Values of TOP in the A horizon were similar between soil types but in the Bt1 and Bt2 horizons, TOP was significantly lower on the Ruston-Gore soil than on the Beauregard-Malbis soil. Values of PAWHC in the A horizon were lower on the Ruston-Gore soil than on the Beauregard-Malbis soil but were unaffected by soil type in the Bt1 and Bt2 horizons.

Textural differences in the A horizon of the Ruston-Gore and Beauregard-Malbis soils (Kerr and others 1980) may have caused PAWHC differences between the two soil types. When compared to the Beauregard-Malbis soil, for example, higher clay contents in the A horizon of the Ruston-Gore soil increased the fraction of total water holding capacity that was unavailable to plants. This, in turn, led to lower PAWHC on the Ruston-Gore soil than on the Beauregard-Malbis soil.

The BD of the Bt1 horizon on the Ruston-Gore soil and the Bt2 horizon of both soil types was ≥ the root growth_limiting value of 1.6 g cm^{-3} (Kelting and others 1999, Pritchett 1979). Values of TOP in the Bt1 and Bt2 horizons continued to decrease by depth on both soil types (table 2). These inherent soil conditions may represent a barrier to

Table 2—Mean bulk density, porosity fractions, and PAWHC of the A, Bt1, and Bt2 horizon at two sapling longleaf pinesites on the Kisatchie National Forest, Rapides Parish, LA

Soil property	Soil type: Ruston-Gore	Soil type: Beauregard-Malbis
	- - - - - - A horizon	- - - - - -
Bulk density (*g cm*$^{-3}$)	1.38 a[1]	1.33 a
Total porosity fraction	0.485 a	0.498 a
Macroporosity fraction	0.298 a	0.236 a
Microporosity fraction	0.188 a	0.263 a
PAWHC (*percent*)	11.6 b	18.5 a
	- - - - - Bt1 horizon	- - - - -
Bulk density (*g cm*$^{-3}$)	1.63 a	1.52 b
Total porosity fraction	0.384 b	0.426 a
Macroporosity fraction	0.081 a	0.155 a
Microporosity fraction	0.308 a	0.271 a
PAWHC (*percent*)	4.5 a	9.4 a
	- - - - - Bt2 horizon	- - - - -
Bulk density (*g cm*$^{-3}$)	1.75 a	1.63 b
Total porosity fraction	0.347 b	0.388 a
Macroporosity fraction	0.067 a	0.087 a
Microporosity fraction	0.282 a	0.302 a
PAWHC (*percent*)	7.1 a	11.2 a

PAWHC = plant-available soil water holding capacity.

The soil at one site is dominated by Ruston fine sandy loam with some Gore silt loam. The soil at the second site is composed of equivalent amounts of Beauregard silt loam and Malbis fine sandy loam.

Means within a soil property and horizon followed by the same letter are not significantly different at $\alpha = 0.10$.

deep root growth that appears to be more limiting on the Ruston-Gore soil than on the Beauregard-Malbis soil. This emphasizes the importance of conducting vegetation management treatments that retain optimal soil conditions for root growth in the A and Bt1 horizons.

CONCLUSIONS

Although this project was recently initiated, some effects of vegetation management treatment were apparent in the Bt1 horizon. Generally, the application of vegetation management treatments that included the chemical control of woody competition resulted in higher BD and lower TOP. We propose that as woody vegetation was suppressed, proliferation of the roots of competing vegetation, and therefore, soil perturbation, were reduced. This led to an increase in BD, a decrease in TOP, and a potential decrease in PAWHC. As long-term biennial prescribed fire continues to control woody competition, BD, TOP and PAWHC may respond similarly. It is likely that these changes in soil properties would reduce the availability of water for tree physiology and growth. Climate changes that lower soil water content could aggravate these limitations. Moreover, differences in soil properties between the two soil types in our study suggest that the potential negative effect of interaction between vegetation management treatment and climate on tree physiology and growth differs by soil type. Research will continue to monitor long-term soil responses to the vegetation management treatments in this study and evaluate relationships between soil responses and longleaf pine physiology and growth.

LITERATURE CITED

Blake, G.R.; Hartge, K.H. 1986. Bulk density. In: Klute, A., ed. Methods of soil analysis part 1: Physical and mineralogical methods, second edition. Madison, WI: Soil Science Society of America, Inc.: 363-375.

Bower, D.R. 1966. Surface soil recovers quickly after burn. Res. Note SO-46. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Research Station. 2 p.

Boyer, W.D. 1987. Volume growth loss: a hidden cost of periodic prescribed burning in longleaf pine? Southern Journal of Applied Forestry. 11: 154-157.

Boyer, W.D.; Miller, J.H. 1994. Effect of burning and brush treatments on nutrient and soil physical properties in young longleaf pine stands. Forest Ecology and Management. 96: 167-183.

Brady, N.C.; Weil, R.R. 2002. The nature and properties of soils, 13th edition. Upper Saddle River, NJ: Prentice Hall. 960 p.

Brockway, D.G.; Lewis, C.E. 1997. Long-term effects of dormant-season prescribed fire on plant community diversity, structure and productivity in a longleaf pine wiregrass ecosystem. Forest Ecology and Management. 96: 167-183.

Duvall, V.L.; Linnartz, N.E. 1967. Influences in grazing and fire on vegetation and soil of longleaf pine bluestem range. Journal of Range Management. 20: 241-247.

Fisher, R.F.; Binkley, D. 2000. Ecology and management of forest soils, third edition. New York: John Wiley and Sons, Inc. 489 p.

Heyward, F. 1939. Some moisture relationships of soils from burned and unburned longleaf pine forests. Soil Science. 47: 313-327.

Johansen, R.W.; Wade, D.D. 1987. Effect of crown scorch on survival and diameter growth of slash pines. Southern Journal of Applied Forestry. 11: 180-184.

Kelting, D.L.; Burger, J.A.; Patterson, S.C. [and others]. 1999. Soil quality assessment in domesticated forests – a southern pine example. Forest Ecology and Management. 122: 167-185.

Kerr, A., Jr.; Griffis, B.J.; Powell, J.W. [and others]. 1980. Soil survey of Rapides Parish Louisiana. U.S. Department of Agriculture, Soil Conservation Service and Forest Service. In cooperation with: Louisiana State University, Louisiana Agricultural Experiment Station. 86 p.

Klute, A. 1986. Water retention: laboratory methods. In: Klute, A. ed. Methods of Soil Analysis Part 1: physical and mineralogical methods, second edition. Madison, WI: Soil Science Society of America, Inc.: 635-660.

Linnartz, N.E.; Hse, C.; Duvall, V.L. 1966. Grazing impairs physical properties of a forest soil in central Louisiana. Journal of Forestry. 64: 239-243.

Lotti, T. 1962. The use of prescribed fire in the silviculture of loblolly pine. In: Proceedings, first annual Tall Timbers fire ecology conference. Tallahassee, FL: Tall Timbers Research Station: 109-121.

Metz, L.J.; Lotti, T.; Klawitter, R.A. 1961. Some effects of prescribed burning on coastal plain forest soil. Sta. Pap. No. 133. Asheville, NC: U.S. Department of Agriculture, Forest Service Southeastern Forest Experiment Station. 10 p.

Moehring, D.M.; Grano, C.X.; Bassett, J.R. 1966. Properties of forested loess soils after repeated prescribed burns. Res. Note SO-40. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 4 p.

Neary, D.G.; Klopatek, C.C.; DeBano, L.F. [and others]. 1999. Fire effects on belowground sustainability: a review and synthesis. Forest Ecology and Management. 122: 51-71.

Neter, J.; Wasserman, W.; Kutner, M.H. 1990. Applied linear statistical models regression, analysis of variance, and experimental designs. Boston, MA: Irwin. 1,181 p.

Outcalt, K.W. 1997. Status of the longleaf pine forests of the West Gulf Coastal Plain. Texas Journal of Science. 49(Supplement): 5-12.

Phillips, D.H.; Foss, J.E.; Buckner, E.R. [and others]. 2000. Response of surface horizons in an oak forest to prescribed burning. Soil Science Society of America Journal. 64: 754-760.

Pritchett, W.L. 1979. Properties and Management of Forest Soils. New York: John Wiley & Sons, Inc. 500 p.

Sword, M.A.; Haywood, J.D. 1999. Effects of crown scorch on longleaf pine fine roots. Gen. Tech. Rep. SRS-30. Ashville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 223-227.

Waldrop, T.A.; Van Lear, D.H.; Lloyd, F.T. [and others]. 1987. Long-term studies of prescribed burning in loblolly pine forests of the southeastern Coastal Plain. Gen. Tech. Rep. SE-45. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 23 p.