Repeated Fire Effects on Soil Physical Properties in Two Young Longleaf Pine Stands on the West Gulf Coastal Plain

Mary Anne Sword-Sayer[1]

[1]USDA Forest Service, Southern Research Station, Pineville, Louisiana, 71360, USA

Introduction

Repeated prescribed fire is a valuable tool for the management of longleaf and loblolly pine. When applied every two to ten years, for example, prescribed fire perpetuates existing longleaf pine ecosystems (Outcalt 1997). Furthermore, the acceptance of fire as a management tool, together with recent improvements in longleaf pine regeneration methods have aided efforts to restore longleaf pine to its natural range (Outcalt 1997, Landers et al. 1995). Low-intensity, prescribed fire every two to five years is also commonly used to manage loblolly pine on public and non-industrial, private land to reduce understory fuel and stimulate the development of wildlife browse.

The response of understory vegetation to repeated prescribed fire over an extended period of time may affect a suite of soil physical properties that influence both the plant-available water holding capacity (PAWHC) and bulk density (BD) of soil. These changes could negatively affect the sustainability of southern pine on the west Gulf coastal plain for two reasons. First, the amount of plant-available water in the soil during drought is already low and any further limitation would increase the likelihood of reduced carbon fixation. Second, these soils are often characterized by a subsurface BD that approaches the root growth-limiting value of 1.55 g/cm^3 (Pritchett 1979). Fire-induced changes in soil porosity that increase BD could restrict root system expansion and therefore, access to water stored deep in the soil profile. In this situation, access to deep water would depend on interped spaces and old root channels in the subsoil (van Lear et al. 2000). Because forest health and sustained production are dependent on the expansion of tree root systems and their acquisition of water and mineral nutrients, continued use of fire as a management tool requires knowledge of its long-term effects on soil physical properties. It is hypothesized that long-term biennial prescribed fire decreases soil porosity which lowers PAWHC and increases BD. The present objective is to summarize the soil physical properties of two young stands of longleaf pine in response to two cycles of biennial prescribed fire.

Materials and Methods

Two field sites are located on the Kisatchie National Forest in central LA. Three replications are located at Site 1, and two replications are located at Site 2. Site 1 is gently sloping (1-3%) and the soil is a Beauregard silt loam and Malbis fine sandy loam complex. The Beauregard soil forms the intermound and wetter portion of the site. The Malbis soil forms slightly elevated pimple mounds. Site 2 has a slope of 1-5% and the soil is Ruston fine sandy loam with some Malbis fine sandy loam and Gore very fine sandy loam. A mixed pine-hardwood forest originally occupied both sites. Site 1 was clearcut harvested, sheared, and windrowed in 1991 and prescribe burned in 1993 and 1996. Understory vegetation at Site 1 is dominated by grasses. Site 2 was clearcut harvested in 1996 and roller-drum chopped and burned in August 1997. Understory vegetation at Site 2 is dominated by woody shrubs and herbaceous plants.

Treatment plots (22 x 22 m; 0.048 ha) were established and blocks were delineated based on 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 late spring every two or three years, and (3) Herbicides (H)-- herbicides were applied after planting for herbaceous and arborescent plant control. Specifically, the H plots at Site 1 were planted in March 1997, and in May 1997 and April 1998, sethoxydim (0.37 kg active ingredient (ai)/ha) and hexazinone (1.12 kg ai/ha) in aqueous solution were applied in 0.9-m bands over the rows of unshielded longleaf pine seedlings. At Site 2, hexazinone (1.12 kg ai/ha) was banded in April 1998 and 1999. At both sites in April 1998 and May 1999, triclopyr (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. The B plots were burned by the strip headfire method in May 1998 at Site 1, and in June 2000, May 2003, and May 2005 at both sites. Container-grown longleaf pine seedlings from a genetically improved, Mississippi seed source (Site 1) and a Louisiana seed source (Site 2), were planted at a spacing of 1.8 x 1.8 m in March 1997 and November 1997, respectively. Treatment plots contained 12 rows of 12 seedlings each. The measurement plots contained the innermost eight rows of eight seedlings in each treatment plot.

In fall of 2004 and spring of 2006, one soil core (61 cm) was extracted from a random location 1 m from the base of three saplings per plot using a tractor-mounted hydraulic probe equipped with an open-sided steel core sampler (1.5 m), 4.1 cm in diameter (72 cores). One additional surface soil core (30.5 cm) was extracted per sapling (72 cores). Soil cores were stored in air-tight, plastic liners and refrigerated until processing. From each 61 cm soil core, three 10 cm depths increments were assessed for physical properties. Depth increments represented the surface soil (A horizon), the upper argillic horizon (Bt1 horizon), and the deeper argillic horizon (Bt2 horizon). The A and Bt2 horizons were evaluated at 2-12 and 50-60 cm depths, respectively. The depth to the interface between the A, AB, E or EB horizon and the Bt1 horizon was visually approximated. The 10 cm depth increment beginning 2 cm beneath this interface was defined as the Bt1 horizon. A second A horizon sample (2-12 cm) from the 30.5 cm soil core was evaluated for soil physical properties.

The integrity of the 10 cm soil core increments was retained while two plastic rings, 1 cm in length and 4.1 cm in diameter, were slid over the core increments. A band saw was used to cut the ring-encased, 1 cm wide slices of soil from the soil core increments. The two slices of soil core from each soil core increment were placed on either a –0.1 MPa or a -1.5 MPa equilibrated, ceramic pressure plate. Total porosity fraction (TOP), microporosity fraction (MIP), macroporosity fraction (MAP), and PAWHC were determined with data generated by the water retention method (Klute 1986) which requires determination of soil water content at field capacity, –0.03 MPa (WATFC), and permanent wilting point, –1.5 MPa (WATWP). Values of BD were determined by the core bulk density method (Blake and Hartge 1986). The BD of the A, and B horizons was calculated as the average of four and two values, respectively. The TOP, MIP, MAP, and PAWHC of the A horizon was calculated as the average of two values.

Values of BD, WATFC, WATWP, TOP, MIP, MAP, and PAWHC were transformed, as needed, to natural logarithms to establish normality, and evaluated by ANOVA 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 $P \leq 0.05$ unless otherwise noted. Means were compared by the Tukey test and considered significantly different at $P \leq 0.05$.

Results and Discussion

Year, block, and treatment significantly affected soil physical properties in the A, Bt1, and Bt2 horizons. The extent of these effects was greater in the A horizon than in the Bt1 and Bt2 horizons. Values of BD in the A, Bt1, and Bt2 horizons were 5, 7, and 8% less in 2006 compared to 2004 (A: 1.4 ± 0.03 g/cm^3; Bt1: 1.6 ± 0.03 g/cm^3; Bt2: 1.7 ± 0.03 g/cm^3). Similar trends were observed with WATFC and WATWP. 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 when the soil was dry and in 2006, soil cores were collected when the soil was wet. The Ultisol soils at the two study sites are characterized by a suite of clay minerals dominated by kaolinite and therefore, exhibit a low shrink-swell potential (Buol et al. 1980, Kerr et al. 1980). However, some soil core expansion was expected after removal from the soil profile due to the influence of organic matter and minor clay minerals on expansion (Buol et al. 1980, Foth 1978). Although small differences in WATFC and WATWP were observed between years, PAWHC within a horizon was similar between years with 19, 10 and 11% of the soil volume potentially accessible as plant-available water in the A, Bt1, and Bt2 horizons, respectively.

Values of BD and WATFC in the A horizon were significantly affected by block. Subsequently, estimated values of TOP, MAP, MIP, and PAWHC in the A horizon were significantly affected by block. These effects exhibited distinct site differences. Specifically, the two blocks at Site 2 were characterized by less WATFC in the A horizon compared to the three blocks at Site 1. This led to 23% less PAWHC in the A horizon at Site 2 compared to Site 1. Significant differences among blocks were also observed in the Bt1 horizon. Both WATFC ($P = 0.0613$) and WATWP were greater in the two blocks at Site 2 compared to the three blocks at Site 1. This resulted in 55% less PAWHC in the Bt1 horizon at Site 2 compared Site 1. It is proposed that these effects were driven by soil texture and organic matter differences between the two sites. Smaller WATFC (24%) and MIP (24%) at Site 2 compared to Site 1 suggests that fractions of silt and sand controlled soil physical properties in the A horizon. Larger WATWP (73%) at Site 2 compared to Site 1 suggests that the clay fraction controlled soil physical properties in the Bt1 horizon. Site differences in understory vegetation may have also affected soil physical properties. With more grass cover at Site 1 compared to Site 2, for example, influences of fine root perturbation on MIP in the A horizon may have been greater at Site 1 compared to Site 2 (Kramer 1983).

Vegetation management treatment significantly affected WATFC and WATWP in the A horizon. Values of WATFC were 16% less on the B and H plots compared to the C plots. Values of WATWP on the H plots were 16% less than that on the C plots, while WATWP was similar on the B and C plots. As a result, estimated values of MAP, MIP, and PAWHC in the A horizon were significantly affected by vegetation management treatment. Values of MAP were 25% greater on the B plots compared to the C plots, while MIP was 17% less on the B and H plots compared to the C plots (Figure 1). The effect of vegetation management treatment on WATFC and MIP was apparent in the PAWHC of the A horizon with 18% less PAWHC on the B and H plots compared to the C plots (Figure 2).

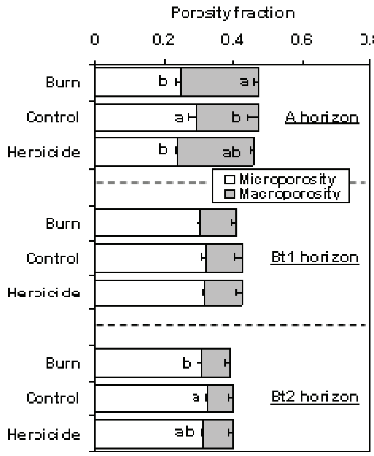

Figure 1. Soil macroporosity (MAP) and microporosity (MIP) of the A, Bt1, and Bt2 horizons in two stands of young longleaf pine in response to three vegetation management treatments. Variable means within a horizon associated with different letters are significantly different at $P = 0.05$ by the Tukey test.

One significant effect of vegetation management treatment was observed in the Bt1 horizon, and two significant effects of vegetation management treatment were observed in the Bt2 horizon. In the Bt1 horizon, the WATWP of the H plots was greater (14%) than that of the B plots. In the Bt2 horizon, WATFC and MIP on the B plots were both 7% less compared to the C plots (Figure 1). These effects on subsurface soil physical properties, however, did not significantly influence PAWHC in the Bt1 or Bt2 horizon (Figure 2). These results suggest that frequent prescribed fire may affect the physical properties that influence PAWHC in the surface soil on west Gulf coastal plain sites. After two cycles of biennial prescribed fire, there was no evidence that these effects had an impact on BD. The mechanism of B and H reductions in WATFC, MIP, and PAWHC in the A horizon may be linked to altered understory vegetation dynamics. Significant block effects that separated soil physical properties by site support this proposition. It is hypothesized that repeated burning in the B plots and chemical eradication of understory vegetation in the H plots reduced fine root perturbation of the soil compared to the C plots. As the influence of fine root activity on soil porosity decreased, the potential of the soil to store water that could be absorbed by tree roots declined. Under normal environmental conditions, small decreases in PAWHC may not impact forest production and health. However, when water availability is limited by prolonged drought, small decreases in PAWHC could create longer periods of water deficit that start earlier in the growing season. We will continue to monitor the long-term response of soil physical properties to B and H, and the present observations will be combined with measurements of physiological function and biomass production to assess the consequence of B and H on longleaf pine physiological health.

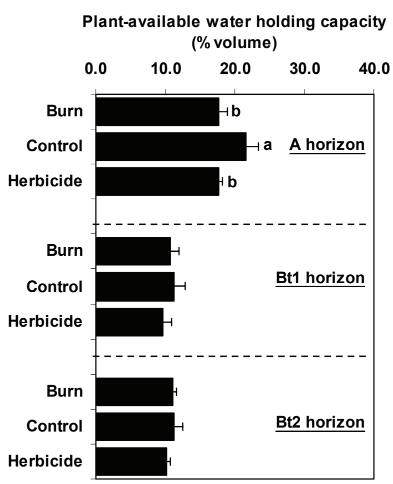

Figure 2. Plant-available soil water holding capacity (PAWHC) of the A, Bt1, and Bt2 horizons in two stands of young longleaf pine in response to three vegetation management treatments. Variable means within a horizon associated with different letters are significantly different at $P = 0.05$ by the Tukey test.

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