PRELIMINARY EFFECTS OF PRESCRIBED BURNING AND THINNING AS FUEL REDUCTION TREATMENTS ON THE PIEDMONT SOILS OF THE CLEMSON EXPERIMENTAL FOREST

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Abstract—This study is a component of the National Fire and Fire Surrogate (NFFS) Study which is an integrated national network of long-term interdisciplinary research to facilitate broad applicability of fuel impacts. This part of the NFFS study in the Piedmont of South Carolina studied three ways of reducing fuel loads (prescribed burning, thinning, and the two in combination). The objective was to determine the effects of prescribed burning and thinning, alone and in combination, on the following soil components: net mineralization and proportional nitrification, C and N concentrations in the O and A/Bt horizons, and bulk density levels of the A/Bt horizon. Of these variables, prescribed burning caused a significant decrease in proportional nitrification, a decrease in carbon and nitrogen concentrations in the O horizon and a decrease in nitrogen in the A/Bt horizon. The thin only and thin and burn treatments caused an increase in bulk density but there was no effect on net mineralization and proportional nitrification. Thinning did not affect the C:N ratio in the O horizon but fire only reduced it and the thin and burn increased it above all other treatments including the control. These functional changes in site quality measurement changes were relatively small and may be only short term for both thinning and prescribed burning.

INTRODUCTION

Over the last several decades, fire suppression on forested lands has been a standard practice. Lack of fire has given rise to a tremendous increase in forest fuel loads and resulted in many large-scale wildfires. In response, the National Fire and Fire Surrogate (NFFS) Study was established to compare ecological and economic impacts of prescribed burning and mechanical fuel-reduction treatments.

Silvicultural practices, such as prescribed burning and thinning, have been shown to have a wide range of effects on soil properties (Ballard 2000, Johnson and Curtis 2001, Phillips and others 2000). The type of harvesting practice may determine the degree of soil disturbance. Generally, clearcutting has been associated with an increase in total site disturbance and soil scarification (Holmes and Zak 1999, Johnson and Curtis 2001, Olsson and others 1996, Prescott 1997, Walley and others 1996). Single tree selection or other types of less intensive thinning do not seem to have any effects on soil properties (excluding some minor changes in bulk density and acute variations in soil chemistry). Johnson and Curtis (2001) found that, on average, forest harvesting in North America had little or no effect on soil carbon (C) and nitrogen (N). Concentrations of C and N may have a slight decrease within the first year of harvesting but it is not substantial or prolonged (Knoepp and Swank 1997). Whole tree harvesting may result in increased bulk density along with decreases in content of organic matter, total N, sulfur, and exchangeable calcium in upper soil layers (Merino and others 1998). These decreases in organic matter lead to a higher potential for soil erosion.

The effects of prescribed burning on most soil characteristics are dependent upon differing levels of fire intensity and frequency. In general, severe burns have a greater effect on soil properties than less severe burns (Bird and others 2000, Covington and Sackett 1992, Vose and others 1999). Prescribed fire results in substantial nutrient losses through immediate volatilization and fly-ash. Hydrolysis of oxides results in increased soil pH, and the duration of this change is influenced by the soil buffering capacity (Ballard 2000). Severe losses of N are attributed to fire (Grogan and others 2000), and Monleon and others (1997) observed a decrease in net N mineralization after prescribed burning. However, these losses are generally brief, with pre-burn N conditions returning within 1 year (DeLuca and Zouhar 2000, Knoepp and Swank 1997, Monleon and others 1997).

The objective of this study was to monitor the effects of prescribed burning and thinning, alone and in combination, on the following soil components: net mineralization and proportional nitrification, C and N concentrations in the O and A/Bt horizons, and bulk density levels of the A/Bt horizon.

METHODS

Experimental Design

A randomized block design, with blocking on tree size class, was used for this study in order to reduce the variability of tree size classes on treatment effects. Each of the three blocks (replicates) contained four sites (treatment areas) that underwent a specific treatment. The four treatments called for by the NFFS included an untreated control, prescribed fire, thinning, and a thinning followed by prescribed fire.

Study Sites

Twelve study sites, one for each treatment in a replicate, were located on the Clemson Experimental Forest in the upper Piedmont of South Carolina. Elevation ranges from

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180 to 275 m above sea level. The parent material of the soil consists of phyllites, granites, gneisses, and various schists formed in the late Precambrian to early Paleozoic age (Sorrels 1984). The soil series are Pacolet (fine, kaolinitic, thermic Typic Kanhapludults), Madison (fine, kaolinitic, thermic, Typic Kanhapludults), Cecil (fine, kaolinitic, thermic Typic Kanhapludults), and Tallapoosa (loamy, mixed, semiactive, thermic, shallow Typic Hapludults).

These study sites were chosen on the basis of stand age, size, and management history. Each of the three replicates was dominated by different size classes of trees. Replication 1 was dominated by pulpwood-sized trees diameter at breast height (d.b.h.) (15 to 25 cm); replication 3 was dominated by sawtimber-sized trees (d.b.h. > 25 cm); and replication 2 was a mixture of both pulpwood and sawtimber-sized trees. Trees on all sites were predominately loblolly (*Pinus taeda* L.) or shortleaf (*Pinus echinata* Mill.) pines with a mixture of hardwoods in the under- and mid-story. Each treatment unit was comprised of a 10-ha measurement area and a buffer of at least one tree length surrounding the measurement area. Within the measurement area, 40 permanent grid points were established. Distance and spacing between each grid point was 50 m in one of the cardinal directions.

Treatments

The levels of prescribed burning and thinning were defined by Fire and Fire Surrogate Study protocols to be sufficiently heavy so that if a wildfire occurred on a day with severe weather conditions (80th percentile for wind and relative humidity) during the wildfire season of the Piedmont of South Carolina, February through early April, 80 percent of the overstory trees would survive.

Burning operations were conducted by the Clemson University Department of Forest Resources with assistance from USDA Forest Service personnel. Prescribed fires set in the burn-only treatment areas occurred in the spring of 2001. A moderate fire intensity was desired in order to remove fuels on the forest floor and some vertical fuels. A combination of strip headfires and flanking fires was used on these sites. Flame heights generally ranged from 0.3 to 4 m. Burning was delayed for 1 year in the thin and burn treatment areas due to an increased risk of high fire intensity associated with heavy fuel loads from thinning. Strip headfires were used on these sites, and flame heights generally ranged from 0.3 to 1.2 m.

Thinning operations were conducted by contract in the winter of 2000 and 2001 and were specified as an operator select mechanized thinning. Small, merchantable-sized trees and diseased or insect-infested trees were selected first. Other trees were removed as necessary to provide a residual basal area of 18 m^2 ha^{-1}. Residual slash was spread over the treatment area.

Soil Sampling

Soil sampling took place within ten 20 x 50 m plots randomly installed throughout each treatment area. From each plot, 20 soil samples were taken (the O horizon and the first 10 cm of mineral soil). Twelve samples (six from the O horizon and six from the A and/or upper Bt horizon) were taken for C and N analysis in the center of six 10 x 10-m subplots. Eight samples were taken from the A horizon at the center of four 10 x 10-m subplots and used to determine net mineralization and proportional nitrification rates. Four of these samples were placed back in the ground for a 20-30 day *in situ* period.

Analysis of C and N concentration levels was contracted to Brookside Laboratories, Inc. A Carlo Erba 1500NA C/N analyzer was used to determine concentrations. Mineralization and nitrification samples were analyzed by KCl extraction. Net mineralization and proportional nitrification were calculated as follows:

Net Mineralization =
(Final NH_4 + Final NO_3) – (Initial NH_4 + Initial NO_3).

Proportional Nitrification =
(Final NO_3 – Initial NO_3) / (Initial NH_4 + Net).

“Initial” refers to samples taken at initial retrieval and “Final” refers to samples collected after the 20-30 day *in situ* period.

There were 10 bulk density samples taken per plot (5 on each 50 m side). The samples were taken starting 5 m from the bottom corner along the long axis of the plot and then every 10 m until the fifth sample was taken. This was repeated on the opposite side of the plot. Each of these sample points was offset 2 to 5 m outside the plot to compensate for boundary soil compaction due to extensive research activity.

After collection, we dried the samples at 104 °C for 16 to 24 hours. We then weighed and calculated the bulk density (gms per cm^3) and averaged the 10 readings by plot to determine mean bulk density (both pre- and post-treatment).

Analytical Procedures

To describe the effect of treatment on these soils, we used Analysis of Variance and Covariate Analysis (SAS 1990). The pre-treatment data were used as covariates in order to take into account pre-treatment differences. Bulk density was the only soil component for which covariate analysis was not used due to a difference in pre- versus post-treatment measurement technique.

RESULTS AND DISCUSSION

Bulk Density

The thin-only bulk density average was significantly greater than the control bulk density average, and the thin and burn was significantly greater than all other treatments (table 1). The increased bulk density associated with thinning may have been caused by compaction due to the use of heavy logging equipment. Froehlich (1978) found most changes in bulk density are associated with the first few trips over the ground without regard to pressure. Increases in bulk density across the thin only treatment areas might have been associated with sampling technique if soil samples were taken in a high proportion of skid trails.

Net Mineralization and Proportional Nitrification

There were no significant differences among treatments for net mineralization (table 2). However, there was a signifi-

Table 1—Bulk density in grams per cm^3

Treatment	Bulk density (actual means)[a]
Control	0.801a ± 0.015
Thin	0.874b ± 0.017
Burn	0.822a ± 0.022
Thin and burn	0.955c ± 0.018

[a] Means followed by the same letter within a column are not significantly different at the 0.05 level.

Table 2—Net mineralization and proportional nitrification levels[a]

Treatment	Net nitrogen mineralization	Proportional nitrification
Control	0.118a ± 0.164	0.092a ± 0.024
Thin	0.356a ± 0.146	0.101a ± 0.030
Burn	0.356a ± 0.157	-0.006b ± 0.028
Thin and burn	0.400a ± 0.134	0.070a ± 0.026

[a] Means followed by the same letter within a column are not significantly different at the 0.05 level.

cant difference among treatments for proportional nitrification. Control, thin-only, and thin and burn treatment areas were significantly greater than the burn-only treatment. Monleon and others (1997) observed immediate decreases in mineralization following prescribed burning. However, mineralization returned to pre-treatment levels within 1 year. The reduction in proportional nitrification in the burn-only but not in the thin and burn treatment areas requires some explanation. The fact that the burn in the thin and burn was done a year after the thin does not necessarily explain the difference. We hypothesize that the previous year's thin produced more woody biomass and organic material which the subsequent burn did not remove, thereby retaining adequate levels of N.

C, N, and C:N Ratios (O Horizon)

Losses of C and N were associated with the three treatment types (table 3). C and N concentrations in the thin-only treatment areas and burn-only treatment areas were not significantly different from each other, but both were significantly less than the control. The C and N concentrations in the thin and burn treatment were significantly less than both these treatments and the control. Because of the much reduced N in the thin and burn treatments, the C:N ratio was significantly increased as compared to all other treatments.

The decreases associated with burning may have been caused by volatilization of N and fly ash losses. The decreases associated with thinning may have been a result of mechanical mixing of the existing pre-treatment O horizon into the A/Bt horizons (Ryan and others 1992). The degree of mixing depends upon total site disturbance. In both the burn-only treatment areas and thin-only treatment areas, these decreases may only be short-term and could return to pre-treatment levels within a short time period.

C, N, and C:N Ratios (A/Bt Horizon)

There were no significant differences in the A/Bt horizon among treatments for C, but differences were noted for N (table 4). N was significantly reduced in the burn-only and thin and burn treatment areas. This significant reduction in N fits the pattern of short-term volatilization losses caused by fire noted in previous studies (Grogan and others 2000). We note, however, that N values less than 0.10 percent were reported as 0. N percent averages were determined using all values including the zero data points. Because there were numerous plots with N values of 0, we did not figure the C:N ratio for these data.

Table 3—Carbon, nitrogen, and C:N for the O horizon (percent excluding ratios)[a]

Treatment	Carbon	Nitrogen	C:N
Control	25.01a ± 0.98	1.02a ± 0.04	24.74ab ± 0.66
Thin	20.34b ± 1.00	0.82b ± 0.04	25.90a ± 0.70
Burn	19.92b ± 1.06	0.79b ± 0.04	23.93b ± 0.66
Thin and burn	16.34c ± 0.99	0.50c ± 0.04	33.64c ± 0.67

[a] Means followed by the same letter within a column are not significantly different at the 0.05 level.

Table 4—Carbon and nitrogen for the A/Bt horizon (percent excluding ratios)[a]

Treatment	Carbon	Nitrogen
Control	2.38a ± 0.14	0.11a ± 0.01
Thin	2.17a ± 0.14	0.09ab ± 0.01
Burn	2.25a ± 0.12	0.07b ± 0.01
Thin and burn	2.07a ± 0.12	0.03c ± 0.01

[a] Means followed by the same letter within a column are not significantly different at the 0.05 level.

CONCLUSIONS

In the short term, the functional site quality measurements on various soil parameters were impacted by thinning and burning. Specifically, fire reduced proportional nitrification, N in the O and A/Bt horizons, and C concentration in the O horizon. Fire did not have an effect on bulk density. Thinning alone had no effect on proportional nitrification, but a reduction on C and N in the O horizon was observed. An increase in bulk density values was associated with thinning. Thin and burn in combination also increased bulk density, reduced C in the O horizon and reduced N below all other treatments in both the O and A/Bt horizons.

Together, the fuel reduction treatments of fire, thinning and the two in combination demonstrate what we might expect from these disturbances in the short-term. Fire reduces C and N especially in the O horizon because of its oxidation of the C and volatilization of the N. We might reasonably expect little effect on bulk density since fire generally has no mechanism to alter this. The fact that thinning did reduce C and N in the O horizon may be explained by the mixing of the O horizon with the mineral soil and the resulting dilution. The subsequent and further significant reduction in C and N due to the combination treatment reflects the apparently additive effects of both treatments.

We note that these effects are not unusually great in magnitude. That is, it is quite probable that pre-treatment levels of both C and N will return in a relatively short time. Furthermore, despite the statistical significance of these effects, the actual values are still within the range of normal Piedmont forest ecosystems. It is doubtful, even if these effects were prolonged, whether there would be any effects on long-term forest productivity. Given that the major intent of this research is to test the value of these fuel reduction methods on a variety of sites nationwide, we conclude, based on these preliminary data, that both are viable methods which have little if any deleterious effect on Piedmont forest soils even in the short-term. As long as these fuel reduction operations are conducted responsibly and in accordance with accepted guidelines as was done in this study, both prescribed fire and thinning appear to be reasonable options which could significantly reduce fuel loads and not damage the soil resource.

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