Reprinted from the *Soil Science Society of America Journal*
Volume 50, no. 2, March–April 1986
677 South Segoe Rd., Madison, WI 53711 USA

Effect of Periodic Burning on Soil Nitrogen Concentrations in Ponderosa Pine

W. W. COVINGTON AND S. S. SACKETT

/

Effect of Periodic Burning on Soil Nitrogen Concentrations in Ponderosa Pine[1]

W. W. Covington and S. S. Sackett[2]

ABSTRACT

To determine the effects of different burning intervals on soil N status in substands of sapling-, pole-, and sawtimber-sized ponderosa pine (*Pinus ponderosa* Laws.) we sampled plots burned at 1-, 2-, and 4-yr intervals by three strata at two depths (0–5 and 5–15 cm). Generally, NH_4^+ and NO_3^- concentrations were higher on plots repeatedly burned than on unburned controls. However, plots not reburned for 4 to 5 yr had concentrations similar to controls. No significant difference in total (organically bound) N was found among treatments. We conclude that frequent periodic burning can be used to enhance N availability in southwestern ponderosa pine sites.

Additional Index Words: **fire effects, NH_4^+, NO_3^-, *Pinus ponderosa* Laws., Arizona, fuel management.**

Covington, W.W., and S.S. Sackett. 1986. Effect of periodic burning on soil nitrogen concentrations in ponderosa pine. Soil Sci. Soc. Am. J. 50:452–457.

Before European settlement of northern Arizona in the 1860s, natural fires were frequent in ponderosa pine (*Pinus ponderosa* Laws.) forests, perhaps occurring every 2 to 3 yr (Dieterich, 1980). For the past 60 to 100 yr fires have been excluded throughout much of this forest due both to active fire suppression and to grazing (which reduced herbaceous fuels and broke the continuity of the forest floor). Decades of fire exclusion in ponderosa pine have been blamed for everything from increased fuel loads, with associated increases in fire severity, to reduced growth and stagnated nutrient cycles (Cooper, 1960; Biswell, 1972; Weaver, 1974). Recently, forest managers have been using prescribed (controlled) burning in the ponderosa pine type, primarily to reduce fuel loads.

Since ponderosa pine growth often is severely limited by low nitrogen (N) availability (e.g., Powers, 1980; Heidmann et al., 1979; Cochran 1979), a major concern has been fire impacts on soil N pools. One concern is the possible decrease in the total N capital of the site because substantial amounts of N may be volatilized during burning (Wright and Heinselman, 1973; Klemmedson, 1976). However, fire exclusion has also been blamed for degrading the N economy (Biswell, 1972; Wright and Heinselman, 1973; Bennett, 1974), by allowing forest litter to steadily accumulate, hence retarding organic N mineralization into NH_4^+ and NO_3^-.

Although some data exist for the effects of initial burning on soil N pools in ponderosa pine (Ryan and Covington, 1986), no data have been published concerning the effects of repeated burning. Since current land management plans for southwestern ponderosa pine include frequent burning for fire hazard control, assessment of the effects of repeated burning on soil N is needed. This paper presents the results of a study of the effects of periodic burning, at 1-, 2- and 4-yr intervals, on total N, ammonium-nitrogen (NH_4^+-N), and nitrate-nitrogen (NO_3^--N) in the mineral soil of a ponderosa pine ecosystem near Flagstaff, AZ. Previous studies at the site had found that fire behavior and ecosystem responses (e.g., changes in moisture, nutrients, and production) varied greatly among patches dominated by saplings, poles, and sawtimber (Harris and Covington, 1983; Covington and Sackett, 1984; Ryan and Covington, 1986). Therefore, the soil sampling scheme and data analysis were designed to compare treatments within the three tree size strata (sapling, pole, and sawtimber).

METHODS

Study Area

The study area is part of the Fort Valley Experimental Forest, approximately 10-km northwest of Flagstaff, AZ, at an elevation of 2195 to 2255 m (11°45′ W, 35°16′ N). The climate is described by Schubert (1974) as subhumid to humid with cool temperatures and early summer drought. Mean annual temperature at the Fort Valley weather station between 1909 and 1968 is 7°C; mean annual precipitation is 57.4 cm, with about half falling as snow. The average frost-free growing season is 94 d.

Soils are derived from basalt and cinders and are tentatively classified as Brolliar stony clay loam (fine montmorillonitic, frigid Typic Argiborolls) by an adjacent soil survey (unpublished soils report by R. T. Meurisse, Coconino National Forest, USDA Forest Service).

The study area, typical of virgin ponderosa pine, is dominated by an uneven-aged forest in small, more or less even-aged groups. Pole-sized trees, 10- to 28-cm diameter at breast height (dbh) and 60- to 100-yr-old, are the predominant size class, with scattered groups of older trees, 28- to 120-cm dbh and 200- to 500-yr-old, and dense thickets of sapling-sized trees ranging from 1.5- to 10-cm dbh and 60- to 70-yr-old. The distribution by size class on the study area was: saplings, 2750/ha; poles, 770/ha; and sawtimber, 130/ha (Sackett, 1980). Trees <1.4-m tall (breast height) were 975/ha. Basal area averaged 33 m^2/ha. The relative canopy area of each overstory stratum on the experimental plots was: sawtimber, 17.3%; pole, 62%; sapling, 17.0%; with 3.7% remaining as small openings (Sackett, 1984).

The site is unharvested except for localized fuelwood cutting of dead trees near roads. Based on fire scar analysis, Dieterich (1980) determined that the last wildfire on the study area occurred in 1876. Before that, fires occurred at an average interval of about 2 yr. Initially, fire exclusion was probably caused by heavy grazing, which began in the 1870s, with active fire suppression beginning just after the turn of the century.

Experimental Design and Treatments

Twenty-seven contiguous 1-ha plots were established in the study area in 1976. Six treatments (periodic burning every 1, 2, 4, 6, 8, and 10 yr) with three replicates each plus controls (and extra unburned plots) were assigned at random to each. Each plot had a 1.5-m wide fireline plowed around its perimeter.

Three separate comparisons of fire effects on soil N were made. First, soils were sampled in the 1-, 2-, and 4-yr in-

[1] Contribution from the School of Forestry, Northern Arizona Univ., Flagstaff, AZ. 86011, and Rocky Mountain Forest and Range Exp. Stn., Fort Collins, CO. Received 22 Feb. 1984.

[2] Associate Professor, School of Forestry, Northern Arizona Univ., and Research Forester, Rocky Mountain Forest and Range Exp. Stn., USDA Forest Service, respectively.

terval plots before the fourth reburning period in the fall of 1980. In 1980 the 1-yr plots had one initial burn and three repeat burns; the 2-yr plots had one initial burn and one repeat burn; and the 4-yr plots had only an initial burn.

Time constraints and an early snowfall precluded our sampling the controls in 1980. Second, to determine the effects of reburning the 4-yr plots, we sampled them and the controls in the spring of 1981. Finally, in the fall of 1981, we sampled the reburned 4-yr plots and the once-burned 10-yr plots, as well as the controls to determine the duration of the reburning effects.

Initial burning treatments were applied at night on 5 Nov. 1976, mostly using strip headfires, with 9 to 12 m between strips, and some backing fires early in the evening (Sackett, 1980). See Brown and Davis (1973) for fire management terminology. Air temperatures dropped from 15°C at 1730 h to 3°C at 2400 h when most of the flaming combustion was complete. Relative humidity increased from 21 to 48% during the same period.

Fuel moisture content was estimated for three layers of the forest floor in accordance with standard fire behavior fuel designations (Brown and Davis, 1973; Sackett, 1979). These layers coincide with earlier forest soils terminology (Lutz and Chandler, 1946) as well. The O1 horizon is separated into the highly flammable L-layer, composed of recently cast litter (mostly pine needles in our case), and the F-layer, litter that is starting to discolor and break down. The O2 horizon is designated as the H-layer in fire behavior considerations. Burning forest floor material had moisture contents of 80 to 120 g/kg in the L-layer, and 100 to 190 g/kg in the F- and H-layers.

Sample Collection

Fuel sampling procedures are described in Sackett (1980). Forest floor weights were determined by collection 64 0.093-m^2 samples per plot, while larger fuels were inventoried by the planar intersect technique of Brown (1974). Forest floor weights are reported as ash-free dry weight (determined by loss on ignition).

Mineral soil samples, composited from 10 to 15 randomly located samples each, were collected from 0- to 5 and 5- to 15-cm depths using a 2.5-cm diam soil sampling tube. For each burning treatment, a total of nine composite samples (three from each replicated 1-ha plot), was taken for each overstory stratum, representing a total of 90 to 135 individual tube samples.

Soils were sieved (2 mm) immediately in the field and a 10- to 20-g subsample for NH_4^+-N and NO_3^--N analysis was added to a 125-mL bottle containing 100 mL of 2 *M* KCL (acidified with HCl to pH = 2.5); the bottle and extractant had been preweighed. The extractant contained 1 mg/kg phenyl mercuric acetate as a preservative. The soil's field weight was determined by a second weighing of the tared bottle and extractant, and its dry weight determined from a second sample dried in a forced air oven at 105°C until weight loss ceased. The remainder of the composite soil sample was placed in a paper bag and returned to the lab where it was air dried for total N analysis.

Chemical Analysis

All N data are reported as elemental N, whether in the organic, NH_4^+, or NO_3^- form, i.e., as either total N, NH_4^+-N, or NO_3^--N. Mineral N was determined colorimetrically on the KCl extract using the Technicon AutoAnalyzer, within 2 d of sampling. An aliquot of the extractant was pipetted into a clean bottle after 24 h of extraction time to prevent contamination from organic matter breakdown. Samples were stored at 1°C before analysis. AutoAnalyzer methods (Anonymous, 1974) were: NO_3^--N, Technicon Industrial Method no. 100–70W; NH_4^+-N, Technicon Industrial Method no. 98–70 W/A; total N, the Berthelot reaction as described by Schuman et al. (1973). For total N, 1 to 2 g of air-dried soil was digested using the selenium-catalyzed, sulfuric acid, hydrogen peroxide, lithium sulfate technique of Parkinson and Allen (1975). The digest was then analyzed on the AutoAnalyzer.

Statistical Analysis

Since factorial analysis of variance (AOV) showed highly significant interactions between treatment, stratum, and depth, one-way AOV's were run for each depth-treatment-stratum-date combination. Statistical comparisons ($p = 0.05$) for a particular sampling date were by Scheffe's test for three means.

RESULTS

Burn Description

The initial fires spread at rates of 1.2 to 1.8 m/min, sometimes increasing to as much as 3.7 m/min. Flame lengths in surface needles seldom exceeded 40 cm. Flaming combustion was evident mostly in surface needles and the upper portion of the F-layer. Glowing combustion was effective in consuming the more decomposed portions of the F- and H-layer, where deep forest floor accumulations were present. On 93% of the area, L-layer material was consumed. F-layer material was consumed on about 61% of the area and H-layer material was consumed on 18% of the area.

Forest floor material <2.5 cm in diameter was reduced from 33.9 to 12.7 Mg/ha by the initial burn. Larger material was reduced from 16.0 to 4.9 Mg/ha by the initial burn. Consumption of forest floor materials was greatest where deep accumulations were burned to mineral soil in groups of old, large trees. Sapling, pole, and sawtimber strata have quite different microclimates and forest floor characteristics, hence they exhibited different fire behavior and consumption rates. The predominant pole-sized stratum had about 52 Mg/ha of material on the ground, whereas open, sawtimber-sized groups had as much as 90 Mg/ha. Dense stands of sapling-sized trees had about 30 Mg/ha. Generally, fire behavior and forest floor consumption were directly related to forest floor loadings. Combustion was greatest in open sawtimber stands, less in closed-canopy pole stands, and least in sapling thickets. The impact of this initial burn on nutrient and organic matter storage in woody litter and forest floor are reported in Covington and Sackett (1984).

Table 1 illustrates the ambient conditions, fire characteristics, and results on fuel loads of repeat burns. Fire behavior during repeat interval burns was different from initial burns due to drastically changed fine fuel conditions. Needle cast after initial burns did not become incorporated with residual forest floor material, in contrast to unburned sites. Instead, 1-, 2-, or 4-yr of needles remained unincorporated on the surface providing more available fuel for flaming combustion and more dramatic fire behavior. However, under marginal burning conditions (damp, cold weather), these unincorporated needles were still difficult to burn. Thus, burning late in the fall, when burning conditions are poorer, drastically reduces the chances for successful prescribed burning.