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Fire exclusion and nitrogen mineralization in low elevation forests of western Montana

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Abstract

Little is known regarding how fire exclusion influences nitrogen (N) cycling in low elevation forests of western Montana. Nor is it clear how the change in fire frequency that has resulted from forest management has influenced ecosystem function in terms of plant–soil–microbe interactions. A fire chronosequence approach was used to examine the influence of forest succession on soil biochemical properties and microbimal activity at 10 sites with varying time since fire (2–130 years). The rate of decomposition of buried tongue depressors and cotton strips, was found to decrease significantly ($R^2=0.410$, $P=0.087$ and $R^2=0.761$, $P=0.003$, respectively) with time since fire (TSF). Net N mineralization and nitrification, as estimated by resin sorbed NH_4^+ and NO_3^- concentrations, both exhibited significant non-linear decreases ($R^2=0.870$, $P=0.000$ and $R^2=0.620$, $P=0.007$, respectively) with TSF. Nitrification potential measured using an aerated soil slurry method, also decreased significantly ($R^2=0.595$, $P=0.009$) with TSF. These decreases in N availability along with an increase in the metabolic quotient and a decrease in labile C pools with TSF indicated a decline in substrate quality and microbial activity with secondary forest succession. The concentration of total phenols in mineral soil showed no significant trend with TSF, but was negatively correlated ($R^2=0.486$, $P=0.025$) with resin sorbed NO_3^- concentration indicating either enhanced immobilization or perhaps chemical inhibition. These results imply that biochemical processes (decomposition and N transformations) may be limited by the lack of available substrate and potentially as a result of rapid immobilization, chemical inhibition or a combination of both at least partially induced by changes in vegetation with TSF. Our results suggest that N availability in ponderosa pine ecosystems of the inland Northwest are directly dependent upon fire history and secondary successional stage.

Keywords: Chronosequence; Nitrogen cycle; Decomposition; Nitrification; Resin capsules; Metabolic quotient; Total phenols

1. Introduction

Although numerous studies have addressed the short-term effect of fire on nutrient cycling in pine ecosystems of the Western United State, there has been almost no attempt made to evaluate the effect of fire exclusion or the length of time since last fire on nitrogen (N) cycling in low elevation forests of the dry inland Northwest. Historic evidence from western Montana suggests that ponderosa pines were maintained by frequent low severity fires that burned every 10–50 years (Arno et al., 1995, 1997; Barrett et al., 1997). Many forests in this region have not experienced fire for over 100 years and thus provide an excellent opportunity to study the effects of fire exclusion on N cycling and microbial activity. In a recent chronosequence study in western Montana (MacKenzie et al., 2004), we showed that concurrent with increases in Douglas-fir basal area, shrubs re-established to co-dominance with grasses and forbs shortly after fire. Herbaceous plants remained in the understory even after 100 years of fire exclusion. These results contrast those of ponderosa pine forests of the southwestern US where fire maintained, grass-dominated understories are eventually replaced by pine needles and bare ground in the absence of fire (White, 1985; Covington and Sackett, 1986; White et al., 1991; Kaye and Hart, 1998). Forest floor properties in the Inland Northwestern US were found to change dramatically with increasing time since fire (TSF) wherein total carbon (C), total N, ammonium (NH_4^+) and potential mineralizable N (PMN) increased with time, while nitrate (NO_3^-) and litter quality decreased (MacKenzie et al., 2004). Given these results, we expect

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mineral soil properties to undergo significant changes as this ponderosa pine/Douglas-fir ecosystem progresses through secondary succession.

A great number of studies have investigated changes in N availability with secondary succession in various ecosystems, however the results are highly variable depending on ecosystem characteristics and to date have not effectively produced a general ecological principle. Studies of deciduous forest generally show increasing N availability with time since disturbance (Bélanger et al., 2004; White et al., 2004) or else exhibit no significant trend at all (Perez et al., 2004). Studies from mixed seral stages of graminoids and deciduous and coniferous forests have generally shown decreasing N availability and reduced nitrification with time since disturbance (Rice and Pancholy, 1972, 1973, 1974; Lodhi, 1977; Lodhi and Killingbeck, 1980; Brais et al., 1995; DeLuca et al., 2002; MacKenzie et al., 2004), but have also shown increasing N mineralization and no inhibition of nitrification (Robertson and Vitousek, 1981; Robertson, 1982; Robertson et al., 1988). Many studies from conifer dominated ecosystems show that litter quality decreases with late secondary succession (Zackrisson et al., 1997; Wardle et al., 1998; Nilsson et al., 2000; MacKenzie et al., 2004) and it is possible that the plant litter associated with these ecosystems has 'after-life' properties which reduce N availability for some time (Northup et al., 1998; Hattenschwiler and Vitousek, 2000).

It is not clear however, whether major attributes of ecosystem function, such as N cycling and microbial activity are closely coupled to the disturbance regime in coniferous forests of the inland Northwest. It is the purpose of this work to examine the effect of fire exclusion on the biochemistry of mineral soil N availability and microbial activity along a fire chronosequence in western Montana. Specifically we tested whether the length of time since fire (TSF) influences (1) decomposition rates; (2) indices of N mineralization; (3) labile C pools; (4) the maximum potential rate of nitrification; and (5) mineral soil total phenol concentration.

2. Materials and methods

2.1. Study sites

Studies were conducted at 10 sites in western Montana of increasing time since fire (2, 24, 45, 78, 87, 92, 122, 132 years since fire). Sites with similar slope, aspect, elevation, and soils at the sub-group level (Table 1) were selected from an earlier chronosequence study (MacKenzie et al., 2004). All sites were located in the Bitterroot National Forest, the Lolo National Forest, and the Blackfoot Clearwater Game Reserve, surrounding Missoula, Montana. Fire dates were determined by the USDA Forest Service by aerial photography, dendrochronology and historic archive material (data not published). At each site, a random coordinate was selected as the starting point 200 m away from any edge or fire boundary and a 100 m transect was laid out for sampling, perpendicular to the main slope. Within each 10 m section of transect, two random numbers were drawn, representing the distance along the transect and the distance to a sampling point, alternating above and below the transect. At all sampling locations, decomposition material and resin capsules were installed as described below and soil samples were collected.

2.2. Decomposition analysis

To measure the rate of cellulose and ligno-cellulose decomposition, one tongue depressor and one cotton strip were installed at the forest floor/soil interface, at the 10 sampling points per transect per site, and left to decompose for 18 months. Cotton strips are primarily made-up of cellulose with a C/N ratio of 300:1, while tongue depressors are made-up of both cellulose and lignin with a C/N ratio of >1000:1. It takes a single enzyme complex to decompose cotton strips (Chew et al., 2001), whereas it takes a suite of enzyme systems to decompose tongue depressors. Therefore, cellulosic materials should decompose far more rapidly than lignified material. However, if the microbial community shifts to favor decomposers of high lignin, low cellulose material, the rate of decomposition of the tongue depressors may increase.

Table 1
Fire chronosequence site descriptions for 10 sites at four locations around western Montana including: time since fire (TSF-sampled in 2002), position on the landscape, pH, and texture soil

Site name	Burn year	TSF (years)	Slope (°)	Aspect (°)	Elevation (m)	pH	Texture[a]
Ninemile	1880	122	10.3	137.0	1218.6	4.36	SL
	1910	92	16.8	175.3	1272.2	4.28	L
	2000	2	13.7	187.0	1181.5	4.85	SL
Clearwater	1880	122	11.0	141.3	1452.9	4.72	SL
	1957	45	8.8	163.1	1457.1	4.78	SL
	1988	24	5.0	172.7	1396.8	4.55	SL
Lost horse	1870	132	11.3	207.0	1393.8	4.22	SL
	1915	87	12.7	143.8	1390.6	4.35	SL
Lake Como	1870	132	15.3	40.7	1678.5	4.27	SL
	1924	78	19.5	106.7	1696.0	4.26	SL

All soils are classified as Typic Dystrocryepts at the sub-group level. Landscape variables are the average of six samples along two different transects, pH is the average of 10 samples along one transect and soil classification is from one soil pit per site.
[a] SL: sandy loam, L: loam.