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Effect of Forest fire on soil nitrogen mineralization and microbial biomass: A review

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Abstract
Fires are one of the main feature of forest disruption and renovation. Different physical, chemical, mineralogical and biological properties of soil is affected by forest fires as a result of burn severity, which consists of peak temperatures and duration of the fire. Forest fires generally reduce the total nutrient pool of a site through some combination of oxidation, volatilization, ash transport, leaching, and erosion. Fire leads to the rapid transformation of organic form of nitrogen to inorganic forms. Fire causes alterations of the abiotic environment, which in turn lead to changes in biotic processes and soil micro fauna. Fire results in increase in nitrogen mineralization rate due to rapid increase of inorganic nitrogen. However, with the passage of time net mineralization decreases due to destruction of organic matter. Further, fire can affect soil microbes directly through heating and indirectly by modifying soil properties. Fire causes a drastic reduction in soil microbial biomass. In general, bacteria are more tolerant to heat than fungi, therefore, it is commonly observed that burning favours bacteria over fungi.

Keywords: Forest Fire, nitrogen mineralization, microbial biomass, soil properties, biological properties

1. Introduction
forests fire is the most common hazard in forests. They cause a threat not only to the forest but also to its entire regime of fauna and flora by seriously disturbing the bio-diversity, ecology and environment of that particular region. Disturbance through fire controls plant community succession and competition; ecophysiology; soils, nutrients, and erosion; and pest behavior (Brown and Smith, 2000) [6]. The effects of fire on a forested landscape are dependent on duration of fire (Shakesby and Doerr, 2006) [39]. As a result of fire loss of vegetation (high burn intensity), increased risk of erosion, soil hydrophobicity, or loss of organic material (high burn severity), and change in wildlife habitat are instantly observed changes. However, with the passage of time after forest fire, vegetation will likely return, soils will stabilize and the ecology of the flora and fauna will progress towards pre-burn conditions.

Forest fires decrease the nutrient pool of a site through some processes such as oxidation, volatilization, ash transport, leaching, and erosion. For example, a low intensity fire reduced nutrient pools in understory and forest floor: 54-75% of N, 37–50% of P, 43–66% of K, 31–34% of Ca, 25–49% of Mg, 25–43% Mn, and 35–54% of B through the process of volatilization and oxidation (Raison *et al.,* 1986) [37]. Some nutrients are more sensitive to fires than others. For example, the concentration of potassium, calcium, and magnesium ions in the soil can be increased or be unaffected by fires whereas nitrogen and sulphur often decrease. Temperature directly controls the amounts and kinds of nutrients that will be volatilized. For instance, in organic matter, N starts volatilizing at only 200º C, whereas Ca needs 1240º C for vaporization to occur (Neary *et al.* 1999) [31]. High intensity fires can also change the physical characteristics of the soil in turn making it more susceptible to nutrient loss through erosion.

Nitrogen mineralization
Alteration in nitrogen cycling as a result of forest fire can tremendously alter ecosystem's structure and functions (Gallant *et al.,* 2003) [19], biogeochemical cycles and productivity (Chorover *et al.,* 1994) [18], as nitrogen is the most essential element limiting plant growth in terrestrial ecosystems (Popova *et al.,* 2013) [35]. Fire acts as a vigorous mineralizing agent, causing the rapid transformation of organic nitrogen to inorganic forms. Fire causes changes in the abiotic environment, which in turn lead to alteration in biotic processes (Raison 1979) [36]. Different studies have attempted to examine the effects of fire on N cycles through the analysis of available N concentrations and N mineralization rates (e.g., Turner *et al.,* 2007; Koyama *et al.,* 2010) [41, 28].

Fires consume N from plants and surface soil layer, resulting in a reduction of N pool in burned forest (Hyodo *et al.,* 2013) [24]. There is an immediate increase in inorganic nitrogen as a

Result of fire (Deluca and Sala, 2006; Koyama *et al.,* 2012; Turner *et al.,* 2007) [15, 29, 41]. However, the immediately increased NH_4^+ can decline to the pre-fire level within one year and the NO_3^- generally returned to pre-fire level within 5 years (Wan *et al.* 2001) [42]. Similar results were observed by Hobbs and Schimel, 1984 [23] in which prescribed burns were carried out in mountain shrub and grass- land communities in the montane zone of the Rocky Mountains in Colorado. Nitrogen mineralization rate was increased in first year after the burn in both communities. Total mineralized soil-N was greater in the burned than unburned areas of both communities during the first growing season after fire.

Duran *et al.* 2009 [18] reported after few years of wildfire occurrence, burned pine forest stands had lower net mineralization rates (both nitrification and ammonification rates) as compared to unburned pine stands. Forest fires significantly reduced the amount and quality of soil organic carbon leaving the recalcitrant organic fraction in the soil. The lower quality of organic matter led to the decrease in net mineralization rates in the burned plots. Other processes such as the depletion of N stocks by large combustion and drainage losses, the reduction of microbial biomass after fire, and fluctuations in the ratio of fungal to bacterial biomass can also be the reason for the low nitrogen mineralization rates after wildfire, (Turner *et al.,* 2007; Bladon *et al.,* 2008) [41, 4]. A rapid increase in nitrogen mineralization rates and microbial activity have been reported after initial post-fire stages as a result of transient increases in temperature, water content, pH, and labile sources of C and N for microbes (Christensen and Muller 1975 and Rutigliano *et al.,* 2007) [9, 32].

Delucha and Zouhar (2000) [14] at three different sites in western Montana also reported that mineralizable N was significantly increased immediately after fire, but decreased to levels lower than the control 1 year after fire. Likewise, microbial biomass N was enhanced rapidly following prescribed burning, but was significantly lower than the control for up to 11 years after prescribed burning. Mineralizable nitrogen was lowered within a year of prescribed fire as a result of nitrogen loss during soil heating, nitrogen loss to plant uptake and leaching losses.

Soil microbes and fire

Soil microbiology is vital for functioning of soil system. Soil micro-organisms checks the transportation of carbon from ecosystems to the atmosphere and therefore influences the balance between terrestrial ecosystems and global climate change. Fire is one of the major element of global climate change which influences the soil microbial communities and, ultimately, their role to the carbon dynamics of terrestrial ecosystems. Soil microbes can be affected by fire directly through heating and indirectly by altering soil properties. Fire resulted in reduction of microbial abundance by an average of 33.2% and fungal abundance by an average of 47.6% (Dooley and Treseder, 2012) [17].

Fire leads to a significant reduction in soil microbial biomass in the short-term (DeBano *et al.,* 1998) [12]. Over the long-term, fire alter soil communities by changing plant community composition (Hart *et al.* 2005) [22]. In general bacteria are more tolerant to heat than fungi (Bollen, 1969) [5], therefore, it is commonly observed that burning favours bacteria over fungi (Sharma, 1981; Deka and Mishra, 1983) [40, 13]. Further, there is an increase of available nutrients in soil after a fire in the form of water-soluble components of ash that become available to living organisms. Also, an increase in the number of N-fixing bacteria after forest fires has been observed (Johnson, 1992) [25].

Due to the increase in frequency and severity of forest fires, more attention has been given to the effects of fire disturbance on soil microbial communities. In a study done by Knelman *et al.* 2015 [27], they examined the effect of *Corydalis aurea*, a common post-fire colonizer plant species on soil chemistry, microbial biomass, soil enzyme activity and bacterial community structure one year after a major forest wildfire in Colorado, USA, in severely burned and lightly burned soils. They reported significant differences in soil edaphic and biotic properties between severe and light burn soils. Further, recolonization of soils by *C. aurea* plants has a significant effect on soil bacterial communities and biogeochemistry in severely burned soils. Therefore, resulting in increases in nitrogen, extractable organic carbon, microbial biomass and shifts in bacterial community diversity.

Soil heating causes the alteration of microbial reproductive capacity and lysing of microbial cells (Covington and DeBano, 1990) [10]. Biological properties of soil are more sensitive to soil heating than chemical and physical soil characteristics, as most of the microorganisms survive at temperature below 100ºC (DeBano *et al.,* 1998) [12]. Effects of fire on soil microorganisms are greatest in the upper soil layers (organic horizon, if present, and upper few cm of mineral soil) where organism are present in abundance (Neary *et al.,* 1999) [31]. Fire can directly alter the size, activity, and composition of the microbial biomass through the process of soil heating. Usually, only 10–15% of the energy released during burning of aboveground organic matter is absorbed by the underlying mineral soil (Raison *et al.,* 1986) [37]. Higher fire intensities and long duration of fire result in greater heat transferred belowground. Unlike the direct heating effects of fire on microbial communities in the short term, the indirect, abiotic effects lead to long-term change in both plant and microbial communities. Indirect effects of fire include increased solar penetration, chemical alteration of the forest floor and mineral soil and the deposition of ash (mostly alkaline oxides) and charcoal. Most of the biological reactions are exponentially related to temperature (Paul and Clark, 1996) [33]; hence, the warmer soil temperatures after fire generally result in increased rates of microbial processes, such as decomposition and nutrient release (Covington and Sackett, 1984; Kaye and Hart, 1998) [11, 26]. Changes in soil moisture after fire also results in changes in the activities of the soil microflora (Paul and Clark, 1996) [33].

Heating of soil decreases the total organic carbon, but increases the pool of soluble organic compounds. The released soluble organic carbon generally acts as readily metabolizable compounds for recolonizating microbes, therefore, allowing a instant increase in populations of microorganisms, mainly heterotrophic bacteria (Badía and Martí 2003 and Guerrero *et al.* 2005) [3]. Some studies reported partial microbial biomass recovery in the first few days after soil heating. Guerrero *et al.* (2005) [21] observed that soil samples exposed at 400 ºC had more microbial biomass (bacteria mainly) than those exposed to 200° and 300 ºC, due to greater abundance of soluble organic carbon. Choromanska and DeLuca (2002) [7] found that the carbon availability in the initial period had significant effects on the recovery (first 14 days) of microbial biomass in heated soils. Pietikäinen *et al.* (2000) [34] intimated that humus samples heated at 160 ºC reported higher values of microbial biomass than samples heated at 100 ºC. Likewise, Badía and Martí (2003) [3] found that after 1 month of incubation, the microbial biomass in a calcareous soil burned at 250ºC was higher than the unburned soil. Heating leads to decrease in soil organic matter and large alteration in its quality. Most of these alteration lead to higher recalcitrance (González-Pérez *et al.* 2004) [20] and thereafter decreases the pool and replenishment rate of the easily mineralized compounds. Therefore, the remaining organic matter is not able to maintain high populations of heterotrophic microbes (main contributors to microbial biomass).

Díaz-Raviña *et al*. (1992) [16] observed a little increase of the microbial biomass in soil heated at 160° and 350 ºC for 30 min during the second week after fire. The low recovery of the mycelium length was suggested to be the reason for the low recovery of biomass. Further, soils heated at 600 ºC, a small recovery of microbes was observed as a consequence of a net decrease in total and soluble organic carbon (Díaz-Raviña *et al*. 1992 and Guerrero *et al*. 2005) [16, 21]. Given the large contribution of fungal biomass to the total microbial biomass (from 30 to 80 percent; Anderson and Domsch 1975) [1], the poor recovery of microbial biomass could be explained by the low recovery of fungi. Most of the field studies reported a decrease in microbial biomass after fire (Palese *et al.* 2004, Mabuhay *et al.* 2006) [32, 30]

Conclusion

Forest fire is an essential component of forest ecosystems. Fires destroy biodiversity directly and have more indirect long-term impacts including the loss of nutrient pool, encouragement of fire and pioneer species. The effect of fire on soil nitrogen mineralization and microbial biomass is highly dependent on the type and intensity of the fire, soil moisture and nature of the burned materials. Therefore, the effect on soil processes and their intensity influenced by fire are highly variable and no generalized tendencies can be suggested for most of the fire-induced changes in soil properties. Forest fires usually decrease the total nutrient pool on a site. From the above cited literature, it can be concluded that mineralizable N was significantly increased immediately following fire, but decreased to levels lower than the undisturbed soils after some time. Further Biological properties of soil are more sensitive to soil heating than chemical and physical soil characteristics, with fatal temperatures for most living organisms occurring below 100 ºC.

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