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Temporal dynamics of carbon and nitrogen in the surface soil and forest floor under different prescribed burning regimes

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ABSTRACT

Prescribed burning has been widely used in the management of forests for reducing wildfire risk, and can have significant effects on soil carbon (C) and nitrogen (N) pools and their temporal changes. This study aimed to investigate the impacts of different burning frequency regimes on the temporal dynamics of C and N in the topsoil and forest floors. The experimental site was a 39 year old wet scherophyll forest prescribed burning trial at Peachester, southeast Queensland, Australia, with treatments of no burning (NB) since 1969, 2 yearly burning (2yrB) and 4 yearly burning (4yrB) since 1972. Each of three burning treatments had four replications and these plots were randomly distributed over an area of the forest with similar vegetation and soil characteristics. Soil (0–10 cm) and forest floors were sampled monthly for 6 months prior to the next scheduled burning for both burning treatments to minimize the effects of fire recency. Prescribed burning significantly ($P < 0.01$) affected most C and N variables in both soils and forest floors. The 2yrB treatment had significantly lower ($P < 0.01$) soil total C, total C:N ratio, microbial biomass C (MBC) and N (MBN), MBC:MBN ratio, dissolved organic C (DOC) and N (DON), NO_3^--N, inorganic N and L layer total N, DON and NO_3^--N, compared with the NB and 4yrB treatments. However, there were no overall significant differences in these variables between the NB and 4yrB treatments. Sampling month significantly ($P < 0.01$) affected C and N variable in both soils and forest floors except for soil total C and N and F layer MBC. Temporal dynamics of most of these labile C and N variables were highly related to soil and forest floor moisture content, seven day mean air temperature (MAT) and cumulative rainfall prior to sampling date. However, fire effects were independent of sampling month, as there were no significant interactions between them for most response variables measured. This study has clearly demonstrated that more frequent burning (2 yr burning) had negative impact on soil and forest floor C and nutrient pools. Insignificant differences observed in soil C and N and forest floor N pools between less frequent burning (4yrB) and NB treatments highlighted that the prescribed burning at four year interval gave sufficient time for recovery of these soil and forest floor nutrients to pre-burn levels.

1. Introduction

Prescribed burning regimes can induce shifts in species composition, reduce number and average height of species (Fairfax et al., 2009; Lewis et al., 2012) and thus may alter ecosystem C and N balance over the long term. Repeated prescribed burning at different intervals may change the temporal dynamics of C and N cycling, possibly via immediate direct loss of C as CO_2 fluxes, N by volatilization and ash convection to the atmosphere (Caon et al., 2014) or indirectly by interacting with variations in rainfall and air temperature in different months which ultimately affects C fixation by vegetation, transfer of C and N from vegetation to the soil (affecting both quantity and chemistry of litters) and soil C and N cycling by changes in microbial population and activity. Variations of rainfall and temperature over different months of the year affect C and N cycling, either directly by influencing soil temperature and moisture, or indirectly by influencing plant production and uptake of water and nutrients (Rastetter et al., 2005; Borken et al., 2006). Significant relationships between soil moisture, rainfall, soil microbial biomass and soil C and N contents in forest ecosystems have been observed (Eaton, 2001; Saynes et al., 2005).

During fire, C and N are lost from the forest floor through volatilization, but the remaining N becomes more available after fire (Wan et al., 2001; Peay et al., 2009) due to thermal breakdown of proteins in the soil, yielding soluble N species such as NH_4^+

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(Moghaddas and Stephens, 2007; Roaldson et al., 2014). With time, this available N is lost by leaching or utilized by plants and microbes and becomes less available gradually (Monleon et al., 1997). Most studies on the effects of wildfire and prescribed burning on the forest floor and soil have focused on the short-term effects following fire (Stephens and Finney, 2002; Hubbard et al., 2004; Certini, 2005; Murphy et al., 2006). Few studies have investigated the effects of repeated prescribed burning and the variation in environmental conditions with time to determine how these factors interact to shape the C and N dynamics of the forest floor and soil (Ponder et al., 2009; Zhou et al., 2009). Changing impacts of prescribed burning with time of sampling are largely unknown, but are critical to understand C and N cycling in forests managed with prescribed burning (Hubbard et al., 2004).

To explore the effects of burning regime and monthly variation, this study aimed to investigate: (1) the long-term effects of prescribed fire frequency regimes on soil and forest floor C and N pools; and (2) the temporal dynamics of these soil and forest floor C and N variables and interactions of fire frequency and sampling month. A 39 year old prescribed burning trial in a wet sclerophyll forest, with repeated burning treatments of different intervals was selected for this study. It should be noted that the latest burning for burning treatments before sampling was conducted in 2005 (for 4 yearly burning plots) and 2007 (for 2 yearly burning plots). The time of soil and forest floor sampling, 3.5 and 5.5 years after last fire event for the 2yrB treatment and 4yrB treatments, respectively (6 months prior to the next fire event for both 2yrB and 4yrB treatments), was chosen to minimize the fire recency's effects. Therefore, this study sought to examine the long-term impacts of prescribed burning treatments on temporal dynamics of soil and forest floor C and N pools. It was hypothesized that (1) prescribed burning would interact with sampling month and consequently different burning regimes would affect soil and forest floor C and N pools differently among different months of the year; and (2) prescribed burning would significantly affect soil and forest floor C and N pools with tendency to have smallest pools under more frequent burning (2 yearly burning) treatment.

2. Materials and methods

2.1. Field site and experimental design

This study used a long-term prescribed burning experimental forest site (Peachester State Forest; lat. 26°50′S, long. 152°53′E) situated about 100 km north of Brisbane in the Sunshine Coast hinterland, southeast Queensland, Australia, a region with a moist sub-tropical climate. The vegetation at the site comprises tall native wet sclerophyll forest dominated by several species of Myrtaceae, especially *Eucalyptus pilularis* (Blackbutt), with other canopy species including *Corymbia intermedia* (bloodwood), *E. microcorys* (tallowwood), *E. resinifera* (red mahogany), *Syncarpia glomulifera* (turpentine) and *Lophostemon confertus* (brush box). The topography is undulating to rolling (2–16% slopes with an easterly aspect). The clay contents of this deep sandy soil increased with soil depth, being 20–28%, 30–40% and 50–60% in the 0–20 cm, 20–60 cm and 60–80% soil layers, respectively. The soil was classified as red to yellow Kandosols (Isbell, 1996) that is equivalent to Alfisols in USDA soil taxonomy.

The prescribed burning experiment was established in 1972 and has treatments of: (1) 2 yearly burning (2yrB); (2) 4 yearly burning (4yrB); and (3) no burning (NB) since 1969. Long unburnt treatment had an understory of rainforest species while burnt treatments had a grassy understory (Lewis et al., 2012). Prescribed fires were carried out in winter and are generally of lower intensity (<2500 kW m^{-1}) and light severity consuming forest floor and understory species during burning but fire not spreading to the tree crown (Lewis et al., 2012; Toberman et al., 2014). The prescribed burning was patchy in nature since small parts of the plot might not be burnt due to topographical conditions (Toberman et al., 2014). There have been no wildfires at the site since 1969, no logging since the 1950s, and no fertilizer application or other silvicultural practices have been applied since the establishment of the burning experiment (Lewis et al., 2012). There are 4 replicate plots (ca. 0.08 ha) for each of the three treatments with a total of 12 plots and these plots are randomly distributed over the experimental area with similar vegetation and soil characteristics (Lewis et al., 2012).

The last prescribed burns prior to sampling were in 2007 in the 2yrB treatment and 2005 in the 4yrB treatment. Scheduled burns for 2009 were not carried out as a result of adverse weather conditions (wind speed, wind direction, air temperature and relative humidity, etc.). As of 2011, the 2yrB treatment had been successfully burnt 17 times and the 4yrB treatment had been burnt 8 times.

2.2. Rainfall and temperature

The whole one year in southeast, Queensland (Australia) is categorized into December-February (summer, average temperature 21–30 °C), March-May (autumn, 15–25 °C), June-August (winter, 11–21 °C), September-November (spring, 15–25 °C). We acknowledge that the six month sampling only covers three seasons (summer, autumn and winter) and is unlikely to take into account all of the seasonal variations occurring within a year. However, this choice of sampling months was made in the light of minimizing fire recency's effects. February indicates late summer, March early autumn, April mid-autumn, May late autumn, June early winter, and July mid-winter.

Meteorological data, including temperature and precipitation, were taken at Beerburrum State Forest Australian Bureau of Meteorology weather station, which is in close proximity to the Peachester site (approximately 14 km away). Seven day cumulative rainfall (CR) and mean atmospheric temperature (MAT) were calculated for the period prior to each sampling. These parameters may reflect the immediate effects of climatic conditions on the C and N cycling processes in the soil and forest floors.

2.3. Soil, L and F layer sampling

Soil, L and F layer samples were collected monthly from the plots at Peachester site over a period from February to July 2011. Soil and forest floor samples were taken on six occasions prior to the next burning event (August 2011) for all three fire treatments (no burning, 2yrB and 4yrB treatments): 9th February, 9th March, 12nd April, 16th May, 15th June and 12nd July. This would minimize the effects of fire recency (e.g. 3.5 and 5.5 years after last fire event for the 2yrB treatment and 4yrB treatments, respectively, as scheduled burns for 2009 were not carried out as a result of adverse weather conditions). This enabled the study to primarily look into the long-term effects of prescribed fire and their interactions with the sampling month. At each sampling time, fifteen surface soil cores (0–10 cm) (Hopmans et al., 2005; Wilson et al., 2002) were collected randomly from each treatment plot using a 7 cm in diameter corer and bulked to produce one composite sample. Field moist soil was sieved (<2 mm) immediately after sampling and stored at field moisture contents in plastic bags at 4 °C prior to measurements of microbial biomass C (MBC) and N (MBN) and dissolved organic C (DOC) and N (DON) and inorganic N (NH_4^+-N, NO_3^--N). A subsample was dried at 105 °C for 24 h, to determine gravimetric soil moisture and all results were expressed on a percentage oven-dry basis. Another subsample was air dried, and finely ground (<150 μm) prior to determination of soil total C and N.