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Responses of labile soil organic carbon and nitrogen pools to long-term prescribed burning regimes in a wet sclerophyll forest of southeast Queensland, Australia

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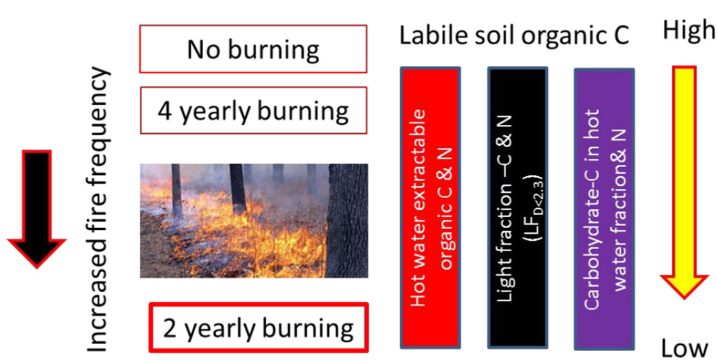
HIGHLIGHTS

- Effects of fire frequency on labile C and N in forest soils were studied.
- 2 yearly burning had lower dissolved organic C and N compared with unburnt treatments.
- Carbohydrates, acid soluble and insoluble organic matters were also lower in 2 yearly burning treatments.
- 2 yearly burning plots had significantly lower $LF_{D<1.6}$ and $LF_{D<2.3}$ dry weight and $LF_{D<2.3}$C and N contents.
- 4 yearly burning and unburnt treatments did not show significant differences.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil labile organic carbon (C) and nitrogen (N) pools play a central role in nutrient cycling, while fire is a key driver of biogeochemical cycle, shaping ecosystem structure and functioning. However, how soil labile organic C and N responds to the long-term repeated prescribed fire is largely unknown. In this study, a prescribed fire field experiment in a wet sclerophyll forest established in 1972 in southeast Queensland was used to evaluate the long-term impacts of different fire frequency regimes on labile organic C and N measured by different extraction methods. The fire frequency regimes included long unburnt (NB), burnt every two years (2yrB) and burnt every four years (4yrB). Results revealed that the 2yrB treatment had significantly lower C and N concentrations in hot water and K_2SO_4 extracts and in density fractions ($LF_{D<2.3}$ and $HF_{D>1.6}$) compared with the NB treatment. Concentrations of carbohydrate-C in hot water extracts and acid soluble and insoluble organic matter-C in cold-water extracts followed a similar trend. The maximum reduction was observed for carbohydrate C (72%) and the hot water extractable N (54%) in the 2yrB treatment compared with the NB treatment, showing these parameters are most sensitive indicators. However, there was no significant difference in most of the above parameters between the 4yrB and the NB treatments, indicating that less frequent fire (4yrB) allows the ecosystem to have sufficient time to recover from fire disturbance and may be a sustainable practice for fire management in this wet sclerophyll forest ecosystem.

1. Introduction

Prescribed burning is a common forest management practice and has been used globally to reduce fuel load (e.g. Thackway et al., 2008).

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Changes in fire frequency can profoundly influence forest soil carbon (C) and nitrogen (N) contents and stocks via changing C and N inputs and outputs (Mastrolonardo et al., 2015; Muqaddas et al., 2015; Vergnoux et al., 2009). Most studies have been short-term and just evaluated effects of single wildfires or prescribed burns or single fire regime (e.g. Hopmans et al., 2005; Neill et al., 2007). Fire can not only changes the total C and N contents but also their distribution among different dissolved and density fractions (Potes et al., 2012; Mastrolonardo et al., 2015). The labile organic C and N pools play a critical role in litter decomposition and nutrient recycling (González-Perez et al., 2004; Li et al., 2017). These labile pools are very sensitive to the environmental changes and management practices compared with the total C and N pools due to the high background values of the total pools and great heterogeneity of soils (Goidts and van Wesemael, 2007). For example, soil dissolved organic C and N and density fractions of C and N responded more rapidly to changes in organic C and N inputs compared to their bulk and recalcitrant fractions (Neff et al., 2002; Zhang et al., 2007). DeLuca and Zouhar (2000) reported that labile organic C (soluble sugar) increased immediately after prescribed fire. González-Perez et al. (2004) reviewed the literature and suggested low intensity prescribed burning might increase the amounts of soil labile organic C. A meta-analysis on the response of soil properties to fire showed that wildfire reduced soil total organic C and total N, but increased microbial biomass C and N and dissolved total C and N in forest ecosystems (Wang et al., 2012), while prescribed burning did not significantly increase soil dissolved organic C and N pools although increasing microbial biomass C and N (Wang et al., 2012). However, the impact of prescribed fires repeated over long periods of time on soil labile organic C and N is still largely unknown. In particular, there is a lack of the detailed study on the fractions of labile C and N in the context of fire impacts.

Separating soil C and N into different soluble and physical pools and examining their individual responses to prescribed burning is a useful way to detect changes in total soil C and N contents in forest ecosystems. Song et al. (2012) used these pools (water extractible organic matter and humic fractions) to detect the effect of forest fires on Mediterranean soils. Chemical methods involve direct extraction with different liquids (water, dilute salt solution and other solvents) to isolate the dissolved components of soil C and N. Generally water extractable C and N pools refer to water-soluble fractions which are recoverable after passing extracting through 0.45 μm membrane. These water extractable C and N pools can be further categorized into hot water extractable (Sparling et al., 1998) or simply water soluble (Chen et al., 2004) depending upon the extraction temperature used. Carbohydrate and acid soluble and insoluble organic matter (ASOM and AIOM, respectively) in soil water extracts can be further isolated using different techniques, such as phenol-method (Boyer and Groffman, 1996; Ghani et al., 2003; Safarik and Santruckova, 1992). Soil carbohydrates may constitute 5 to 25% of soil organic matter (Stevenson, 1994). They act as cementing agents, represent a large part of the labile soil C in soil organic matter and may be greatly affected by land management practices (Guggenberger et al., 1995), resulting in degraded soil structure (Cheshire et al., 1983). Miesel et al. (2015) found that carbohydrate stocks in forest mineral horizons decreased with severity level of fire. Most previous research only studies effects of wildfires on soil carbohydrate C (e.g. Martín et al., 2009; Alexis et al., 2010; Potes et al., 2010). Analyzing water extractable fractions can give estimates of fire-induced changes in physiochemical properties of organic matter (Santos et al., 2016), especially for prescribed fires which has been less studied.

Physical fractionation methods involve the use of densiometric techniques to isolate the light fraction (LF) or others fractions. The LF provides an important labile reservoir of C and N in forest ecosystems (Spycher et al., 1983). This fraction comprises mostly organic residues in various stages of decomposition and has a high concentration of organic C and N relative to that of the whole soil (Theodorou, 1990). The LF mainly consists of free organic matter (Spycher et al., 1983) whereas the heavy fraction (HF) includes clay and associated organic materials. Most of the LF originates from plant residues, but it also contains an appreciable quantity of microbial debris including fungal hyphae and spores (Spycher et al., 1983). The LF has a much higher turnover rate than the bulk organic matter (Six et al., 2002) and is more sensitive to management practices than total organic matter in the soil (He et al., 2008). Potes et al. (2012) reported that annual pasture burning did not affect C, N and C:N ratios in all density fractions up to the 15 cm of soil depth but promoted a redistribution of soil C stocks from the occluded fraction to the heavy fraction in the 0–5 cm soil layer. Heckman et al. (2013) concluded that fire did not significantly change C contents and the distribution of soil organic matter between heavy and light fractions. Mastrolonardo et al. (2015) used physical fractionation (1.8 Mg m^{-3} as density cut-off) to differentiate free aggregate from the occluded aggregates as affected by fire severity, and found that fires broke up soil aggregates, leading to the release of some occluded soil organic matter (SOM). Identifying the physical fractions of SOM into different pools and quantitatively analyzing changes in these pools are critical for better understanding C and N dynamics and their responses to change in management (Zimmermann et al., 2007). Soil isotopic signatures have been previously used to infer patterns of fire history (Aranibar et al., 2003). Stable isotope signatures of soil N indicate patterns of N cycling as affected by fire (Robinson, 2001). The response of the stable isotope signature of SOM to fire is still a matter of debate and more studies are needed to understand stable carbon and nitrogen isotope fractionation during vegetation fires (Certini et al., 2011).

In this study we used a long-term prescribed burning experiment established in 1972, with treatments of no burning (NB), burning at two-year intervals (2yrB) and burning at four-year intervals (4yrB). Previous studies have documented that the most frequent prescribed burning treatment resulted in lower soil total C and N contents (Liu et al., 2013; Muqaddas et al., 2015) as well as reduced acid hydrolysable and permanganate oxidizable C and N pools (Muqaddas et al., 2015). However, how these changes in soil total C and N are distributed among contrasting dissolved pools (Ghani et al., 2003; Vergnoux et al., 2011) and density fractions remains unclear. But, analysis of only two labile indicators does not provide an accurate evaluation of what is driving soil C and N alteration (Vergnoux et al., 2009). Therefore, the present study aimed to assess the effects of long-term burning regimes on soil labile C and N pools as indicated by dissolved organic C and N pools (DOC, DON) and light fractions. The evaluation of relationships between C and N of different labile pools may further suggest which pool is driving the variations in others (Song et al., 2012). We expected the results from this study would give detailed insight into C and N distribution in different pools and their changes occurring in response to fires. It was hypothesized that more frequent prescribed burning (i.e. 2yrB) would result in lower C and N contents in all dissolved pools and density fractions. As a result, in this study, different methods (physical and chemical) used to isolate and evaluate the changes in C and N contents in different fractions in response to prescribed burning frequency.

2. Materials and methods

2.1. Field site and experimental design

This study used a long-term prescribed burning experiment near Peachester, southeast Queensland, Australia (26°52′S, 152°51′E), a region with a moist sub-tropical climate (Fig. 1a, b). The vegetation at the site is a tall forest dominated by several species of Myrtaceae, especially *Eucalyptus pilularis* (Blackbutt), with other canopy species including *Corymbia intermedia* (pink bloodwood), *E. microcorys* (tallowood), *E. resinifera* (red mahogany), *Syncarpia glomulifera* (turpentine), and *Lophostemon confertus* (brush box). The deep sandy soils were classified as red to yellow Kandosols (Isbell, 1996) (equivalent to Alfisols in USDA soil taxonomy).