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Long-term frequent prescribed fire decreases surface soil carbon and nitrogen pools in a wet sclerophyll forest of Southeast Queensland, Australia

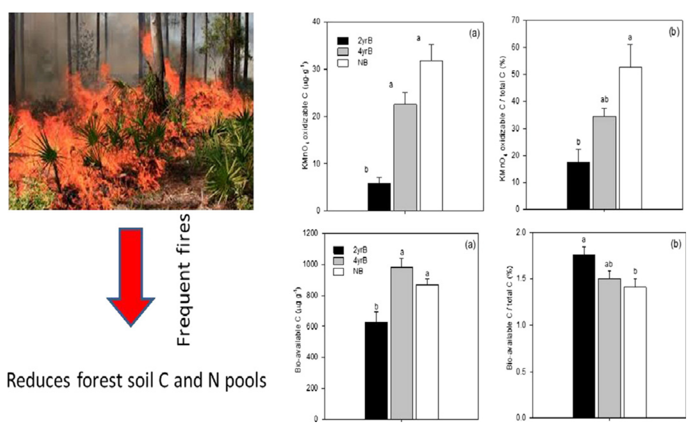
Bushra Muqaddas [a], Xiaoqi Zhou [a], Tom Lewis [b], Clyde Wild [a], Chengrong Chen [a,*]

[a] Griffith School of Environment and Environmental Futures Research Institute, Griffith University, Nathan 4111, Australia
[b] Department of Agriculture, Fisheries and Forestry University of the Sunshine Coast, Sippy Downs Drive, Sippy Downs, QLD 4556, Australia

HIGHLIGHTS

- Effects of fire frequency regimes on carbon and nitrogen in forest soils were studied.
- 2 yearly burning lowered all soil C and N pools compared with unburnt treatments.
- 4 yearly burning and unburnt treatments showed no significant differences.
- Prescribed burning at four year interval is a more sustainable management practice.

GRAPHICAL ABSTRACT



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ABSTRACT

Prescribed fire is one of the most widely-used management tools for reducing fuel loads in managed forests. However the long-term effects of repeated prescribed fires on soil carbon (C) and nitrogen (N) pools are poorly understood. This study aimed to investigate how different fire frequency regimes influence C and N pools in the surface soils (0–10 cm). A prescribed fire field experiment in a wet sclerophyll forest established in 1972 in southeast Queensland was used in this study. The fire frequency regimes included long unburnt (NB), burnt every 2 years (2yrB) and burnt every 4 years (4yrB), with four replications. Compared with the NB treatment, the 2yrB treatment lowered soil total C by 44%, total N by 54%, HCl hydrolysable C and N by 48% and 59%, $KMnO_4$ oxidizable C by 81%, microbial biomass C and N by 42% and 33%, cumulative CO_2–C by 28%, NaOCl-non-oxidizable C and N by 41% and 51%, and charcoal-C by 17%, respectively. The 4yrB and NB treatments showed no significant differences for these soil C and N pools. All soil labile, biologically active and recalcitrant and total C and N pools were correlated positively with each other and with soil moisture content, but negatively correlated with soil pH. The C:N ratios of different C and N pools were greater in the burned treatments than in the NB treatments. This study has highlighted that the prescribed burning at four year interval is a more sustainable management practice for this subtropical forest ecosystem.

* Corresponding author at: Griffith School of Environment, Griffith University, Nathan, QLD 4111, Australia.
E-mail address: c.chen@griffith.edu.au (C. Chen).

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1. Introduction

Fire is an important driver of environmental changes in an ecosystem affecting nutrient pools by changing the quantity and chemistry of substrates (González-Pérez et al., 2008). Prescribed burning is a widely-used practice to reduce fuel loads on forest floor and thus the risk of wildfire, especially in Australia (Reverchon et al., 2012) where approximately 4.7 million hectares of forest were burnt through planned fires in the period 2001–2006 (Thackway et al., 2008). Given forest ecosystems contain approximately half of the total terrestrial C pool (1.15×10^{18} g) (Dixon et al., 1994), any minor changes in soil C contents due to wildfire will have great effects on atmospheric CO_2 concentrations (De la Rosa et al., 2008).

Soil consists of different C and N pools with varying turnover rates. Soil labile C and N pools are characterized by their small quantities and fast turnover rates (i.e. from months to several years). They are mainly derived from plant litter decomposition and root exudates and play an important role in nutrient cycling (Hu et al., 1997). Recalcitrant organic C and N pools are physically or chemically protected with longer turnover rates. Recalcitrant organic C, such as inert charcoal, a prominent component of fire-affected ecosystems (Poirier et al., 2000), has a turnover time on a scale of hundreds or thousands of years. However, labile C and N pools are sensitive to management practices (Zhang et al., 2007) and hence are likely to be influenced by different fire regimes such as prescribed burning.

The influence of prescribed fires on soil C and N varies with fire frequency and intensity. Low intensity prescribed burning has been shown to increase the amounts of labile C (Gonzalez-Perez et al., 2004), but repeated prescribed forest burning might cause a reduction in forest labile C and N pools and biologically active C fractions (Schloter et al., 2003). Prescribed fire may also affect microbial community composition and function (Cerda and Solera, 2009) and thus alter C and N cycling (Artz et al., 2009) in a forest ecosystem. An improved understanding of the response of soil labile and biologically active C and N pools to different prescribed burning regimes is therefore needed for predicting future changes in forest C and N cycling. Many studies have focused on the short-term effects of prescribed burning on total C and N pools (Hopmans et al., 2005), fluxes of greenhouse gases and biological properties (Wiedinymer et al., 2006).

Soil C and N cycles may however be altered by long-term frequent burning due to removal of litter, consequent soil erosion, volatilization of nutrients and shifts in soil microbial activity (e.g. Knicker et al., 2005). However information on the long-term effects of prescribed fire frequency on the amount and nature of soil C and N pools is limited (Williams et al., 2012). Forest fire can cause considerable rearrangement of soil C forms (Gonzalez-Perez et al., 2004). Prescribed burning is thought to increase heat-resistant complex C and N compounds by converting non-resistant forms to resistant forms (Knicker et al., 2005). Given that recalcitrant organic C (e.g. oxidation-resistant organic C and charcoal C forms) has a much longer mean residence time than labile C (Schulze et al., 2000), an improved understanding of the role played by recalcitrant C in eucalypt forests in the context of prescribed burning is required as the processes govern C flux and forest productivity (Attiwill and Adams, 2008).

A long-term prescribed burning experiment site in a wet sclerophyll forest southeastern Queensland Australia, was used for this study. Previous studies at this site have shown that prescribed burning treatments led to changes in the composition of both plant species and soil microbial communities and reduced microbial activity and fungal biomass (Bastias et al., 2006; Lewis et al., 2012). Guinto et al. (2001) reported considerable losses in soil total N induced by burning every two years at this site and recommended that the effects of repeated fire regimes on soil organic C and N pools be further investigated in detail. In the present study, we aimed to determine the effects of repeated prescribed fire on soil labile, biologically active and recalcitrant C and N pools, using various chemical extractions methods. We hypothesized that the long-term repeated prescribed fire would (1) result in lower soil labile, biologically active C and N pools, the extent of effects being greater for more frequent fire (burning every 2 years) than for less frequent fire (burning every 4 years); and (2) lead to the shifts in chemical composition and biological nature of soil C and N pools, with a tendency to have more recalcitrant organic C found in the soils under more frequent fire (i.e. burning every 2 years).

2. Materials & 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. The vegetation at the site comprises tall forest was dominated by several species of Myrtaceae, especially *Eucalyptus pilularis* (Blackbutt), but also including *Corymbia intermedia*, *Eucalyptus microcorys*, *Eucalyptus resinifera*, *Syncarpia glomulifera* and *Lophostemon confertus*. The deep sandy soils were classified as red to yellow Kandosols (Isbell, 1996) (equivalent to Alfisols in USDA soil taxonomy).

The prescribed burning experimental site was established in 1972 and has treatments of: (1) burning every two years on average (2yrB); (2) burning every four years on average (4yrB); and (3) no burning (NB) since 1969. Prescribed fires were carried out in winter and were generally of low intensity (<2500 kW m^{-1}) and patchy in nature (Lewis et al., 2012; Hannah et al., 2014). There were four replicate plots (0.08 ha) of each treatment randomly distributed over an area of the forest 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. As of 2007 and 2005, 17 burns had been implemented in the 2yrB and eight burns in the 4yrB treatment respectively.

2.2. Soil sampling

Soil sampling was conducted in January 2011 approximately 3.5 and 5.5 years after the last prescribed burns in 2yrB and 4yrB burnt treatments, respectively. Scheduled burns for 2009 were not carried out as a result of adverse weather and the next burn at both fire frequencies was scheduled for winter 2011. Fifteen cores of surface soil samples (0–10 cm) were randomly collected from each plot using a 7.5 cm diameter auger. These fifteen samples were bulked to one composite sample, packed in polyethylene bags, and immediately transported to the laboratory. Soil samples were then sieved to fine earth (<2 mm diameter), and any visible pieces of plant materials and debris were removed manually. Half of each processed sample was stored at 4 °C for microbial biomass C and N measurements. The remaining soil was air dried for chemical analysis.

2.3. Soil analyses

2.3.1. Basic soil properties, C and N contents

Soil pH and electrical conductivity (EC) were determined in 1:5 (v/v) soil/water extracts using a combination glass electrode. Gravimetric moisture content was determined from weight loss after drying at 105 °C for 48 h and dividing by dry mass. Finely ground (<150 μm) air-dried soil samples were used for determining total C and N by dry combustion method using isotope ratio mass spectrometer with a Eurovector Elemental Analyser (Isoprime-EuroEA 3000, Milan, Italy).

2.3.2. Soil C and N pools

2.3.2.1. Labile. Acid hydrolysis and oxidation methods were used to determine labile soil C and N pools. Acid hydrolysable soil labile C and N