

Role of soil drying in nitrogen mineralization and microbial community function in semi-arid grasslands of north-west Australia

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Abstract

We examined effects of wetting and then progressive drying on nitrogen (N) mineralization rates and microbial community composition, biomass and activity of soils from spinifex (*Triodia* R. Br.) grasslands of the semi-arid Pilbara region of northern Australia. We compared soils under and between spinifex hummocks and also examined impacts of fire history on soils over a 28 d laboratory incubation. Soil water potentials were initially adjusted to -100 kPa and monitored as soils dried. We estimated N mineralization by measuring changes in amounts of nitrate (NO_3^- -N) and ammonium (NH_4^+ -N) over time and with change in soil water potential. Microbial activity was assessed by amounts of CO_2 respired. Phospholipid fatty acid (PLFA) analyses were used to characterize shifts in microbial community composition during soil drying. Net N mineralized under hummocks was twice that of open spaces between hummocks and mineralization rates followed first-order kinetics. An initial N mineralization flush following re-wetting accounted for more than 90% of the total amount of N mineralized during the incubation. Initial microbial biomass under hummocks was twice that of open areas between hummocks, but after 28 d microbial biomass was $<2 \mu\text{g}^{-1}$ ninhydrin N regardless of position. Respiration of CO_2 from soils under hummocks was more than double that of soils from between hummocks. N mineralization, microbial biomass and microbial activity were negligible once soils had dried to -1000 kPa. Microbial community composition was also significantly different between 0 and 28 d of the incubation but was not influenced by burning treatment or position. Regression analysis showed that soil water potential, microbial biomass N, NO_3^- -N, % C and $\delta^{15}\text{N}$ all explained significant proportions of the variance in microbial community composition when modelled individually. However, sequential multiple regression analysis determined only microbial biomass was significant in explaining variance of microbial community compositions. Nitrogen mineralization rates and microbial biomass did not differ between burned and unburned sites suggesting that any effects of fire are mostly short-lived. We conclude that the highly labile nature of much of soil organic N in these semi-arid grasslands provides a ready substrate for N mineralization. However, process rates are likely to be primarily limited by the amount of substrate available as well as water availability and less so by substrate quality or microbial community composition.

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1. Introduction

A greater understanding of mechanisms that govern carbon (C) and nitrogen (N) mineralization is essential for semi-arid regions where the sporadic nature of rainfall results in cycles of soil wetting followed by extended dry

periods (Evans and Ehleringer, 1994; Fierer and Schimel, 2002). The arid and semi-arid regions of Australia are characterized by spinifex (hummock grasses), which cover almost one-third of the continent (Allan and Southgate, 2002). Spinifex is dominated by the genus *Triodia* R. Br. and all species have distinctive sclerophyllous leaves that intertwine to form a large dome-shaped hummock (Fig. 1a). Growth of *Triodia* is limited to immediately after significant rainfall events and is confined to the outer part of the hummock (Allan and Southgate, 2002). Dead plant material accumulates within and underneath the

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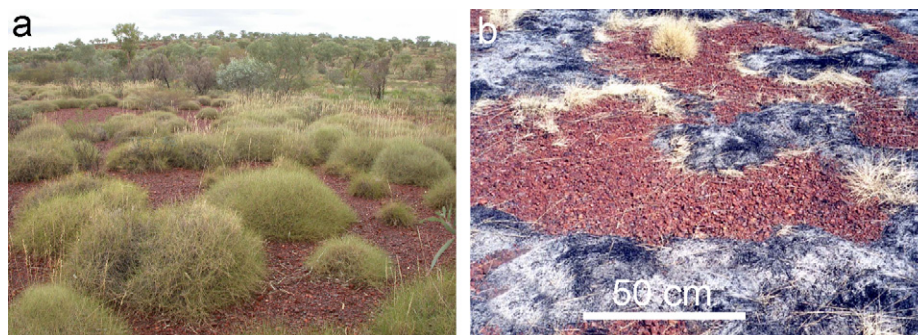


Fig. 1. Hummocks of *Triodia* in the Pilbara, Western Australia: (a) intact hummocks and (b) hummocks after fire, showing discrete patches of ash deposition.

hummock (Rice and Westoby, 1999) in a manner similar to other semi-arid ecosystems including semi-arid shrublands and grasslands (Charley and West, 1975; Schlesinger et al., 1996; Bennett and Adams, 1999). This growth and senescence pattern results in a patchy mosaic of substrates potentially available for mineralization (Charley and West, 1977; Hook et al., 1991). Organic matter content also influences bulk density and water-holding capacity of soils that in turn influence microbial biomass and activity (Howard and Howard, 1993; Paul et al., 2003). Given this heterogeneous distribution of organic matter, we expect soil C and N mineralization in hummock grasslands to be highly localized.

Microbes play an essential role in C and N cycling primarily by facilitating the maintenance of pools of available nutrients in terrestrial ecosystems (Gallardo and Schlesinger, 1992; Balser and Firestone, 2005). However, soil microbial activity is often constrained by the availability of water within the soil matrix (Skopp et al., 1990; Schjønning et al., 1999) especially in arid and semi-arid regions. Progressive soil drying gradually confines soil water to smaller films around soil particles, leading to increasingly negative soil water potentials, and reducing substrate diffusion to microbes (Stark and Firestone, 1995). Under these conditions, microbes expend more energy to assimilate water (Skujins, 1984) and maintain internal water potentials equal to the surrounding soil via accumulation of solutes (Wilson and Griffin, 1975; Harris, 1981). Therefore, at low water potentials microbial function may be inhibited by high intracellular concentrations of solutes (Stark and Firestone, 1995) and reduced access to C substrates (Kieft et al., 1987; Skopp et al., 1990). Given this, we expected that microbial activity would be greater in areas of higher substrate availability, such as beneath *Triodia* hummocks, when water availability was high compared with soil between hummocks. Conversely, with progressive drying we expected a gradual dissipation in the spatial variability of microbial activity as substrate availability becomes restricted in both soil from under and between hummocks.

Accumulation of dried spinifex biomass and the resinous nature of the foliage of many species of *Triodia* (Burrows

et al., 1991) ensure spinifex communities are highly flammable. Fire in spinifex grasslands is both frequent and extensive, often exceeding 10,000 km² in a single fire (Allan and Southgate, 2002). However, the effect of fire on soil microbial activity in *Triodia* grasslands is largely undescribed, despite the geographic dominance of this grassland type in Australia (Allan and Southgate, 2002). *Triodia* hummocks burn in on themselves creating localized soil heating and ash deposition (Westoby et al., 1988; Fig. 1b), which likely produces changes in the quality and quantity of organic matter presented to soil microbes (Neary et al., 1999; Smithwick et al., 2005a) and that may decrease microbial substrate heterogeneity, relative to unburned sites. As the availability of organic substrates will mediate microbial activity, fire induced changes to organic substrates is also more likely to affect C and N cycling under high water availability.

The responses of microbes to sporadic rainfall events and then subsequent decreasing water availability as soils dry, will vary with taxon. However, with decreasing water availability a smaller proportion of the microbial community is likely to be active. As such, the composition of the active microbial community may also become more similar (converge) with decreases in water availability. Furthermore, the spatial variability in soil organic matter content that characterizes most semi-arid grasslands is also likely to give rise to spatially distinct microbial communities that differ in composition (Kuske et al., 2002; Bossio et al., 2005). However, relationships among the soil properties that likely regulate spatial variability in composition of the microbial community in semi-arid and arid environments remain largely undescribed. Changes in soil metabolic activity may represent a change in the composition of the microbial community (Zogg et al., 1997). Therefore, we propose that those soil properties that regulate microbial-mediated C and N cycling are also likely to regulate microbial community composition. As these relationships are likely to have feedback mechanisms the composition of the microbial community is also likely to mediate microbial function (Zogg et al., 1997).

The objective of our study was to clarify mechanisms of C and N cycling and microbial community composition in

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