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Rewetting and litter addition influence mineralisation and microbial communities in soils from a semi-arid intermittent stream

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ABSTRACT

Nitrogen (N) and carbon (C) mineralisation are triggered by pulses of water availability in arid and semi-arid systems. Intermittent streams and their associated riparian communities are obvious 'hot spots' for biogeochemical processes in arid landscapes where water and often C are limiting. Stream landscapes are characterized by highly heterogeneous soils that may respond variably to rewetting. We used a laboratory incubation to quantify how N and C mineralisation in rewetted soils and sediments from an intermittent stream in the semi-arid Pilbara region of north-west Australia varied with saturation level and substrate addition (as ground *Eucalyptus* litter). Full (100%) saturation was defined as the maximum gravimetric moisture content (%) achieved in free-draining soils and sediments after rewetting, with 50% saturation defined as half this value. We estimated rates and amounts of N mineralised from changes in inorganic N and microbial respiration as CO_2 efflux throughout the incubation. In soils and sediments subject to 50% saturation, >90% of N mineralised accumulated within the first 7 d of incubation, compared to only 48% when soils were fully saturated (100% saturation). Mineralisation rates and microbial respiration were similar in riparian and floodplain soils, and channel sediments. N mineralisation rates in litter-amended soils and sediments (0.73 mg N kg^{-1} d^{-1}) were only one-third that of unamended samples (3.04 mg N kg^{-1} d^{-1}), while cumulative microbial respiration was doubled in litter-amended soils, suggesting N was more rapidly immobilized. Landscape position was less important in controlling microbial activity than soil saturation when water-filled pore space (% WFPS) was greater than 40%. Our results suggest that large pulses of water availability resulting in full soil saturation cause a slower release of mineralisation products, compared to small pulse events that stimulate a rapid cycle of C and N mineralisation–immobilization.

1. Introduction

Stream landscapes, and particularly their associated riparian zones, are known to be hot spots for primary productivity in dryland (arid and semi-arid) environments, supporting the transformation and retention of nutrients (Pinay et al., 1992; Schade et al., 2002). However, in contrast to more mesic systems, the functional relationships between nitrogen (N) and carbon (C) mineralisation, water pulses and ecosystem dynamics for intermittent streams in arid environments are not well understood (Fierer and Schimel, 2002; Bechtold and Naiman, 2006; Collins et al., 2008). During infrequent flood events, dry channel beds are inundated with substantial volumes of floodwater for days or weeks, and subsequent overland and overbank flow may stimulate productivity in adjacent riparian zones and floodplains (Junk et al., 1989; Baldwin and Mitchell, 2000). Low relief in many semi-arid landscapes, including in Australia, generates a complex of anastomosing channels and riparia. The subsequent differences in the quantity and quality of organic matter (OM) inputs, soil texture, and water retention across the stream landscape thus create a stratified mosaic of potential microbial substrates (Pringle et al., 1988; Thoms and Sheldon, 2000). In addition, the extent and duration of any flood pulse are likely to act as major controls on which ecosystem components and processes are active and to what degree (Cable and Huxman, 2004).

Post-flooding, drying of soils and sediments may cause divergence in mineralisation potential across the stream landscape as local substrate availability and physiochemical characteristics increase in importance. Substrate quantity, rather than substrate quality or microbial community composition, may be a primary control in determining N and C process rates in regions where OM inputs are low and soils are intrinsically nutrient-poor (Cookson

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et al., 2006; Ford et al., 2007). While there is an increasing interest in the influence of rewetting on nutrient release from dry soils (e.g. Grierson et al., 1998; Fierer and Schimel, 2002; Miller et al., 2005), most of these studies have focussed on upland ecosystems. Relatively few studies have examined semi-arid stream landscapes, such that a quantitative and mechanistic understanding of mineralisation in these systems is lacking.

Microbes play an essential role in N and C cycling, and facilitate maintenance of pools of bioavailable nutrients in terrestrial ecosystems (Gallardo and Schlesinger, 1995; Balser and Firestone, 2005). The relationship between water availability and microbial processes in soils and sediments is complex, and varies according to soil texture, moisture retention, porosity, OM content, pH and depth (Goncalves and Carlyle, 1994; Rodrigo et al., 1997; Leiros et al., 1999). In semi-arid systems, microbial activity is particularly affected by changes in moisture availability, and rewetting may cause large and rapid increases in the rate of microbial respiration and nutrient mineralisation (Lund and Gorksoyr, 1980; Orchard and Cook, 1983; Kieft et al., 1987; Sparling et al., 1995; Fierer and Schimel, 2002; Collins et al., 2008). In contrast, full saturation of soils usually limits the activity of obligate aerobic microbes, and favours other processes such as denitrification and ammonification (Groffman and Tiedje, 1991; Zhang and Wienhold, 2002). During drying, several interrelated mechanisms cause a decrease in microbial activity; these include reduced diffusion of soluble substrates and lowered microbial mobility, and direct physiological effects on microbial growth (Paul et al., 2003). Regardless of other factors, microbial respiration is expected to be greatly reduced at soil water potentials less than −1000 kPa (Zak et al., 1999; Fierer et al., 2003; Ford et al., 2007). While responses of microbes to drying vary by taxon, declining substrate and water availabilities are likely to favour fewer taxa, and microbial community profiles may therefore converge among soils and sediments in different parts of any given landscape.

The objective of our study was to quantify microbial responses and N and C mineralisation across a rewetting–drying cycle for soils and sediments from an intermittent stream landscape. In particular, we sought to determine the relative role of three factors: water availability, substrate availability and position in the stream landscape (zone), on microbial communities and N and C mineralisation. We hypothesized that: (i) mineralisation and microbial variables (biomass, activity, diversity, community structure) are regulated equally by water availability, substrate availability and landscape position; (ii) riparian soils will have greater rates of N and C transformation and microbial activity in response to rewetting in comparison to floodplain soils and channel sediments; (iii) mineralisation and microbial activity will be reduced under saturated (100% gravimetric moisture content in free-draining soils) conditions, but increased under moderate (50% gravimetric moisture content in free-draining soils) saturation; and (iv) onset of substrate limitation would be rapid in unamended soils and sediments during incubation, owing to their naturally low content of available nutrients.

2. Materials and methods

2.1. Site description

The Pilbara region of north-west Western Australia encompasses approximately 26 million ha, and has a climate ranging from semi-arid to subtropical, with mild winters averaging 11–24 °C and hot summers averaging 26–40 °C (Bureau of Meteorology, 2008). Rainfall is highly variable among seasons and years (mean ∼350 mm y^{-1}, CV = 45%), with the majority contributed by summer cyclone activity (Bureau of Meteorology, 2008). The Pilbara is characterized by hydrologic extremes – droughts may persist for many years or even decades, followed by extreme floods that may inundate hundreds of square km (Department of Water, 2004). Evaporation exceeds precipitation, often by more than one order of magnitude, and soil temperatures commonly exceed 40 °C in summer. The Pilbara has extremely weathered soil profiles overlying rocks of Archaean (∼3.6 billion years old) origin (Geoscience Australia, 2007), resulting in low soil content of phosphorus (P) and N (Bentley et al., 1999; Ford et al., 2007). Total soil N of less than 0.07% and labile P of less than 0.004% are common (Islam et al., 1999; Ford et al., 2007).

Soil and sediments were collected from Barnett Creek (22°30′05 S, 117°41′37 E) on Hamersley Station, 14 km north-west of Tom Price (Fig. 1). Barnett Creek is an unregulated, lowland floodplain stream, which flows ephemerally into the main channel of the Ashburton River. The creek forms a braided, anabranching pattern typical of many lowland dryland rivers, with a gravel and cobble channel bed, and sandy floodplain capped with lateritic gravel and calcrete outcrops. Floodplain vegetation is dominated by spinifex hummock grasses (*Triodia* spp.) and *Eremophila* shrubs, while the riparian zone has dense stands of the leguminous tree *Acacia citrinoviridis* Tindale & Maslin with a mixed tussock grass understorey (species include *Eulalia aurea* (Bory) Kunth and *Themeda triandra* Forssk.), and *Eucalyptus camaldulensis* Dehnh, and *Eucalyptus victrix* L.A.S. Johnson & K.D. Hill lining channels. For our study, zones were delineated by vegetation community type and cover. Vegetation community transitions between adjacent zones tended to be abrupt and easily recognizable in the field.

2.2. Field sampling design

Three cross-channel transects were established perpendicular to the two main channels of Barnett Creek (Fig. 1). Transects extended across the channel beds, encompassing the adjacent riparian zone and extending ∼10 m into the floodplain on either side of the creek. Soils and sediments were collected at randomly selected points along the three transects, with 20 sample points for each of three zones (channel, riparian and floodplain). At each sampling point, approximately 500 g of soil or sediment was collected from the top 0–2 cm of the profile, which was then sieved to <2 mm in the field, and air-dried. Soils were collected for moisture retention curves in November 2005, while soils for the incubation experiment were collected in August 2006. The last significant floods in Barnett Creek were in March 2004 and February 2006. Typical physical and chemical characteristics for soils and sediments from each of the three zones are summarized in Table 1.

2.3. Soil moisture retention, saturation treatments and water-filled pore space

Moisture retention curves (McIntyre et al., in press) for channel, riparian and floodplain soils and sediments were developed using the ceramic pressure plate method (Cresswell and Hamilton, 2002), with equilibration at four different water potentials: −0.1, −10, −100 and −1500 kPa. The 100% and 50% saturation points were then identified from the curves for each of the three zones. 100% saturation was defined as the maximum gravimetric moisture content (%) achieved in the free-draining soils and sediments after rewetting, with 50% saturation defined as half this value (Table 2). At Barnett Creek, these saturation levels would correspond to a major flood and moderate rains, respectively. Equivalent matric potentials (kPa) were calculated using the moisture retention curves, and water-filled pore space (% WFPS) using the following formula (1) (Gardner, 1994):

$$\%\text{WFPS} = [P_W \times (D_B/S_t)] \times 100 \quad (1)$$