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Reestablishment of ecological functioning by mulching and termite invasion in a degraded soil in an Australian savanna

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ABSTRACT

Soil degradation is a major source of ecological dysfunction in both natural and agricultural landscapes. Termites are key mediators of tropical soil structure and function, but there has been little experimental evaluation of their potential in soil rehabilitation. This study investigated if termite activity can be used as a tool to improve the properties and function of degraded soil in tropical Australia, through mulch addition. A 2 × 2 randomised block design was used, with mulch (bare [B] or mulched [M] plots) and termiticide (termite [T] or non-termite [NT] plots) as factors. Over 4.5 years I tested the hypothesis that the MT plots would show greatest increase in (i) soil macroporosity, (ii) total soil surface carbon and nitrogen, (iii) litter decomposition, (iv) soil water storage and (v) plant cover, and (vi) greatest reduction in soil strength. MT treatment plots showed a 46% and 45% increase in soil macroporosity and plant cover, respectively, and a 25% reduction in soil strength compared with MNT plots. Compared with B treatments (BT, BNT), macroporosity and plant cover were 98% and 60% higher, respectively and soil water storage increased by up to 15%. Termites contributed to 58% of litter loss in MT plots over the transitional/dry season period. Mulching doubled soil carbon and nitrogen levels. This research demonstrates termite-mediated processes can be initiated and maintained in degraded soil, thereby improving soil structure and key ecosystem functions. Termites may represent a valuable biological resource for promoting tropical soil restoration, through incorporating techniques that promote their activity into tropical soil rehabilitation management.

1. Introduction

With increasing population growth, climate change and a history of anthropogenic mismanagement and overexploitation of limited resources, soil degradation has become one of the most significant global environmental challenges (Lal and Steward, 1990; Suzuki et al., 2007). Degraded soils require rehabilitation through human intervention if ecosystem services are to be restored and productivity sustained (Lal, 1988; Doran and Zeiss, 2000). One mechanism to assist this process may be through understanding and manipulating the soil fauna.

The basic ecosystem functions of capturing, retaining and recycling water, nutrients and carbon largely occur within the soil domain. These processes are fundamental to landscape sustainability and productivity, and therefore restoring these processes is critical to the rehabilitation of degraded landscapes (Lavelle and Spain, 2001; Dawes-Gromadzki, 2005a; Lavelle et al., 2006).

Soil macroinvertebrates are an integral component of healthy soils, and in the tropics termites are key mediators of these ecosystem services (Lobry de Bruyn and Conacher, 1990; Gillison et al., 2003). Through their activities they maintain and improve the physical, chemical and biological qualities of soil. The dense network of channels they create and maintain improves soil porosity and aeration, and through bioturbation they modify soil chemical characteristics by mixing soil from different layers (Lobry de Bruyn and Conacher, 1990; Holt and Lepage, 2000). As such they are critical in governing processes such as water infiltration and storage, decomposition, nutrient and carbon cycling, and consequently primary productivity supported by the soil (Holt and Coventry, 1990; Lavelle, 1997; Dawes-Gromadzki, 2005a).

In the tropics termite activity is therefore likely to reverse some of the very processes that lead to the deterioration of soil quality, thus indirectly helping to prevent or slow the rate of soil degradation (Lal, 1988). However despite the widespread recognition of the contribution of termites to soil health and function, there is little experimental evidence of the mechanisms and use of termite-mediated processes in land management, ecosystem productivity and soil rehabilitation (Mando et al., 1999).

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Most evidence comes from the semi-arid and arid tropics of Africa, where experiments have demonstrated that mulch can be used as a sustainable restoration practice for crusted soils, through the stimulation of termite activity (Mando et al., 1996). In West Africa termite-mediated processes have led to increased water infiltration and storage, decomposition, soil carbon, water use efficiency and productivity (Léonard and Rajot, 1997; Rouland et al., 2003; Ouédraogo et al., 2007).

This paper describes an experiment designed to test empirically if termites could be used to aid the restoration of soil function in a degraded Australian tropical savanna. Traditionally Australia's tropical landscapes have been recognised as relatively intact ecologically, and thus globally unique (Williams et al., 1997). However, their sustainability is now under threat as the symptoms of soil degradation, such as erosion and reduced water quality, have become apparent (McCulloch et al., 2003). Termites play an important role in the provision of soil ecosystem services in tropical Australia where they dominate soil macrofauna abundance and biomass (Holt and Coventry, 1990; Lee and Foster, 1991; Dawes-Gromadzki, 2007). However to date there has been no investigation of their role in soil rehabilitation.

The overall goal of this study is to test if the physical, chemical and biological attributes of degraded soil can be improved by promoting termite activity through mulch addition. The hypothesis tested was that mulching degraded soil will indirectly attract termites, leading to an increase in (i) soil macroporosity, (ii) total soil surface carbon and nitrogen, (iii) litter decomposition, (iv) soil water storage and (v) plant cover, and to (vi) a reduction in soil resistance to penetration.

2. Materials and methods

2.1. Study site

The study was conducted from November 2001 to July 2006 at the CSIRO Tropical Ecosystems Research Centre (12°25′S, 130°53′E) near Darwin in the Northern Territory, Australia. The climate is monsoonal with a mean annual rainfall of 1715 mm (November–April). Mean daily maximum and minimum temperatures are 31.9 °C and 23.2 °C respectively (Bureau of Meteorology). The vegetation is open forest (Specht, 1981) dominated by *Eucalyptus miniata* Cunn. ex Schauer and *Eucalyptus* F. Muell., over a ground layer of annual and perennial grasses. The soil is a petroferric brown kandosol (Isbell, 2002). The experiment was conducted in a 2200 m^2 area of severely degraded savanna that had been cleared annually with a mechanical grader for over 25 years. The entire area is represented by bare soil with no signs of macroinvertebrate activity evident.

2.2. Experimental design

The study was designed as a randomised complete block with five replicate blocks, each with four 5 × 5 m plots as experimental units. Blocks were separated by 10 m and plots in a block by 5 m. The experiment was a 2 × 2 factorial with the two levels of each factor yielding a total of four treatments. The two factors were straw mulch (either bare [B] or mulched [M] plots) and termiticide (either termite [T] or non-termite [NT] plots). The four treatments (BT, MT, BNT and MNT) were randomly allocated to the four plots within each block. The BT treatment represents the control.

The termiticide Bifenthrin was used to prevent termites entering NT treatments. This is one of the most persistent termiticides under field conditions (Horwood, 2007). The two NT treatment plots in each block (BNT, MNT) were treated with Bifenthrin in November 2001 at an application rate of 75 kg ha^{-1}. Straw mulch was applied after 48 h to the two M treatment plots in each block (MT, MNT) at a rate of 12,000 kg ha^{-1}, covering the soil surface to a depth of 10 cm. Due to decomposition, mulch was applied annually at the same rate from 2002 to 2005.

Termite activity using wood baits, soil water storage and litter decomposition was monitored over the study period. Soil macroinvertebrates were sampled in 2005 and 2006, and soil carbon and nitrogen, macroporosity, soil resistance and vegetation cover were also quantified towards the end of the experiment.

2.3. Soil macroinvertebrates

During the last two years of the experiment, soil pits were used to assess the effects of the treatments on soil macroinvertebrates. Sampling was conducted in late March/early April of 2005 and 2006, when annual soil macroinvertebrate activity in this region is high. Three 25 × 25 × 10 cm deep soil pits were randomly dug in each plot and the excavated soil then hand-sorted in the laboratory. Macroinvertebrates were classified to class, order and suborder (Harvey and Yen, 1997). Taxa comprising less than 2% of total specimens were pooled into a single group labelled ‘other’. Soil pit sampling was not performed earlier in the experiment due to the level of plot disturbance this would have created.

2.4. Termites

In mulch treatments (MT, MNT) baits were used to assess the termite fauna and the effectiveness of the termiticide treatment. Eight wooden stakes (40 × 35 × 300 mm long seasoned, untreated *Eucalyptus regnans* F. Muell.) were placed in direct contact with the soil surface (Dawes-Gromadzki, 2003). Baits were not used in bare treatments as they would have acted as a surrogate food-addition treatment.

Two bait sampling periods were carried out, referred to hereafter as Bait Period 1 (BP1) and Bait Period 2 (BP2). For BP1 baits were installed in April 2002 and periodically inspected from May 2002 until July 2004 when they were collected, as many in MT plots were almost or completely consumed. BP2 baits were then installed and periodically sampled from August 2004 to July 2006. Baits were inspected every 1.5–2 months with a total of 12 inspections during BP1 and 13 for BP2. At each inspection baits were lifted, the intensity of foraging activity was assessed and baits replaced in their original positions. Soldier castes were collected for species identification.

Frequency of termite occurrence was measured as the percentage of the eight baits in each plot that had been attacked, as indicated by the presence of termites, carton (woody faecal material) and/or characteristic termite-mediated cavities where termites had consumed variable amounts of the substrate. Intensity of termite foraging activity was quantified on a visual area basis by assigning a score of one of six ‘Intensity of Attack’ ratings: 0 = no attack (stake intact), 1 = 1–24% of bait consumed, 2 = 25–49% of bait consumed, 3 = 50–74% of bait consumed, 4 = 75–99% bait consumed, 5 = bait consumed completely or replaced by gallery and/or carton material (Dawes-Gromadzki, 2003; Dawes-Gromadzki and Spain, 2003). When baits were first installed a log of *Eucalyptus camaldulensis* Dehnh. (800 mm long × 200 mm diameter) was placed in each mulched plot. This acted as a larger food source to potentially increase the termite species diversity sampled. Logs were inspected at every bait census. These data were combined with those from stake baits for species-level analyses.

Termites were identified to species using keys and descriptions from Hill (1942) and Miller (1991) and by comparisons with voucher specimens held at CSIRO. Termite species were also assigned to a functional feeding group (Dawes-Gromadzki, 2008),