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BIENNIAL CONFERENCE**

Official publication of The Australian Rangeland Society

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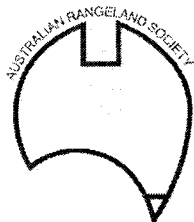
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SOIL CRUST CYANOBACTERIA MODERATE PLANT-AVAILABLE NITROGEN DURING DROUGHTS

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ABSTRACT

Biological fixation of nitrogen by cyanobacteria is believed to be a significant source of plant available nitrogen in arid ecosystems. This study was carried out in south-western Queensland and obtained basic data on nitrogen mineralisation from soils where cyanobacteria are a significant component of the soil surface ecosystem. Our results indicated that mineralisable nitrogen was always greater in the surface soil, irrespective of seasonal condition, and was significantly greater on the crust type with a sandy covering compared with the surfaces devoid of sand. We conclude that during drought, small falls of rain combined with dew are sufficient to maintain cyanobacteria in an active state. The sandy covering over the crust probably stimulates nitrogen production by creating anaerobic conditions that also reduce the loss of gaseous nitrogen through volatilisation.

INTRODUCTION

Cyanobacteria are photosynthetic prokaryotes known to be highly resilient to changes in their physical and chemical environment. Biological fixation of nitrogen by cyanobacteria is believed to be a significant source of plant available nitrogen in arid ecosystems (Sheilds *et al.*, 1957). Many soil-inhabiting cyanobacteria fix atmospheric nitrogen by using specialised cells called heterocysts that convert atmospheric nitrogen to ammonium (NH_4^+), a form that is potentially useable by plants. Heterocysts in cyanobacteria exclude oxygen, providing the necessary anaerobic environment required for nitrogen fixation. Charley (1972) acknowledged that micro-organisms were probably making a substantial contribution to the nitrification process after rainfall, but the exact mechanisms involved, or the organisms responsible, were not well understood. Subsequent studies have indicated that soil-and rock-inhabiting cyanobacteria and lichens are an important source of nitrogen in desert environments (Shachak *et al.* 1987), particularly where nitrogen-fixing plants (legumes) are not a major component of the vegetation.

Cyanobacterial-dominated soil crusts occupy large areas of apparently bare interspaces between plants in the semi-arid subtropical rangelands of south-western Queensland. These crusts are critically important for maintaining landscape stability, particularly during droughts. While it has long been suspected that crusts are important sources of nitrogen for these desert soils, and thus a source of mineralisable nitrogen for desert plants, to date the mechanisms are poorly known and the relative importance of crusts not well quantified. The aim of the study reported here is to measure nitrogen mineralisation rates from soils where cyanobacteria are a significant component of the soil surface ecosystem. We were particularly interested in comparing rates over two different periods; 1) when cyanobacterial activity would be predicted to be low (droughts or below-average rainfall periods), and 2) when cyanobacterial activity would be high (post-drought).

METHODS

The study was carried out within Glencoban Bore paddock (28°10'S; 146°02'E) in the Gilruth Land System in south-western Queensland. This 2000 ha paddock has extremely low relief, and consists of lightly banded groves of *Acacia aneura* or *Eucalyptus populnea* in low lying run-on zones with large, inter-grove run-off zones dominated by stony red earths supporting perennial grasses. Land use is domestic stock (sheep and cattle). Cyanobacterial soil crusts dominate the bare patches between vascular plants, surviving in a climate of extended dry spells, drought, intermittent storms, and floods. Rain falls predominantly during the summer months, and averages 370 mm annually. In winter therefore, dews are the primary source of moisture for these soil crusts.

Cyanobacterial crust samples to be tested for mineralisable nitrogen were collected during the latter phase of severe drought and again six months into post-drought recovery. At least three replicates were selected from each different landscape surface type, i.e. (a) sandy run-off, (b) partly stony run-off, (c) stony run-off. Samples were then categorised into three different cyanobacterial crust types: (1) sand over crust, (2) light-coloured thin crust and (3) dark-coloured thick crust. Within a 0.5 m² quadrat four 10 cm x 10 cm samples were collected from each landscape surface type at two depths and directly below each other at 0-1 cm and 1-5 cm. Samples were mixed thoroughly, sieved, and stored in airtight clip-lock plastic bags (soil samples contained less than 0.5% moisture at time of sampling). Crust samples were also taken from within the quadrats to identify the species of cyanobacteria present.

Laboratory analyses for mineralisable nitrogen were carried out using Gianello & Bremner (1987) Method 4 procedure. General Linear Modelling (Minitab 1997) was used to test for differences in mineralisable nitrogen between the three crust types, three landscape surfaces, two depths and two sampling periods, and their interactions after diagnostic tests were performed to check for homogeneity of variance (Levene's test). *Post-hoc* differences in means were determined using Least Significant Difference tests.

RESULTS

Stigonema ocellatum, *Scytonema* sp. and *Gloeocapsopsis dvoraki* were the known dominant N-fixing cyanobacteria, and were found within 45% of light-coloured thin crusts and more than half of the dark-coloured thick crusts.

Across the run-off zones, mineralisable nitrogen was always greater in the surface soil ($P < 0.001$), but there were no significant effect of surface type ($P = 0.075$, Figure 1). There were significantly higher concentrations of mineralisable nitrogen during the drought compared with after the drought ($P = 0.002$). During the drought, mineralisable nitrogen was significantly greater on the crust surfaces covered with a thin layer of sand compared with the surfaces devoid of sand, which were generally not significant from each other ($P > 0.05$; Figure 1). This trend was also evident after the drought, but only in the 1-5 cm layer (Figure 1). Mineralisable nitrogen was always greater in the surface soil, irrespective of seasonal conditions. This translates to maximum values of mineralisable nitrogen occurring at a rate of 0.87 kg N/ha.

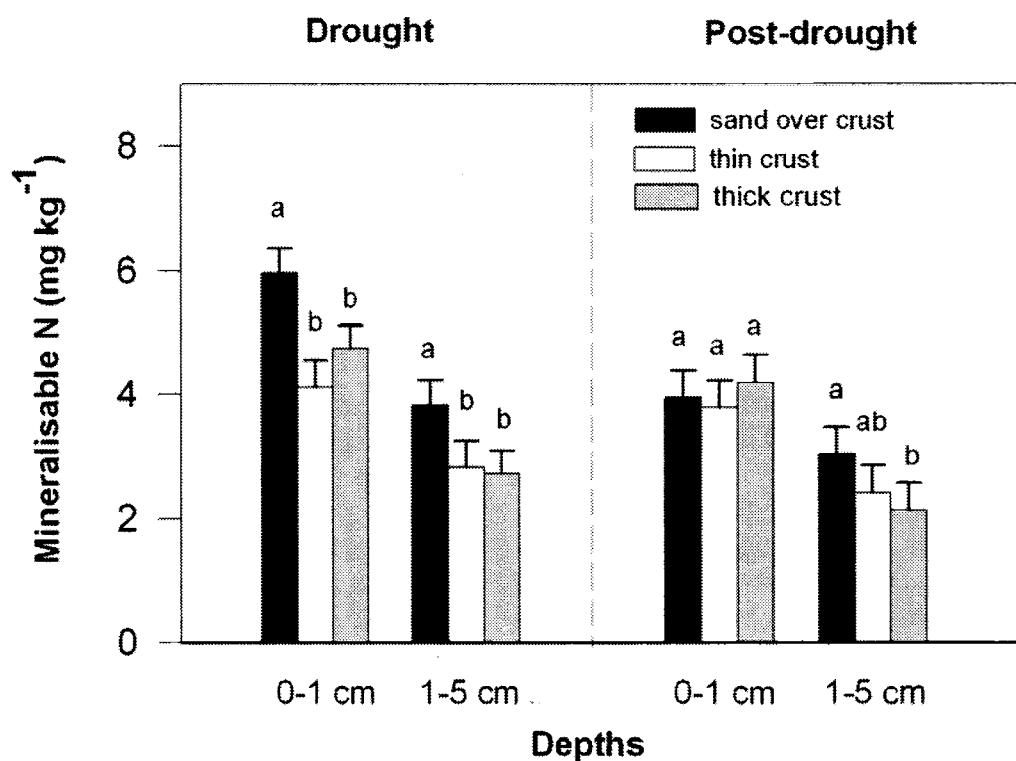


Figure 1: Mean (+ standard error of the mean) mineralisable nitrogen (mg/kg) for two depths and three crust types during and after drought

Within a depth class at a given time, different letters indicate a significant difference in mineralisable nitrogen between crust types at $P < 0.05$

DISCUSSION

Our results show that cyanobacterial soil crusts covered in a thin layer of sand and surviving in the run-off zones during drought had double the mineralisable nitrogen compared with cyanobacteria at other times and locations during and after drought. With the progression of drought, the process of wind and water erosion resulted in accumulation of thin layers of sand over the crust surface. Our field measurements have shown that there was 28% more intact cyanobacterial crust under the sand compared with surfaces where sand was absent (Williams, 2004). Therefore, rather than representing a degraded surface, this covering of sand appeared to have a positive effect on the N accumulation in the upper soil profile during drought, even at depth. We believe that the presence of a thin layer of sand may provide an anaerobic environment conducive to the production of N by cyanobacteria.

Cyanobacteria are known to respond rapidly to wetting (Rascher *et al.* 2003), and during droughts, this moisture comes in the form of light rains of only a few millimetres or the winter dews that occur frequently during drought periods. Our studies have shown that these levels of moisture, insufficient to provide a response in vascular plants, are sufficient to stimulate a response in the cyanobacterium and presumably nitrogen fixation. Thus drought may present an ideal opportunity for cyanobacteria to fix nitrogen, particularly in a form which is available to vascular plants. It would also appear that the nitrogen that may normally be lost through denitrification and volatilisation might be trapped beneath the sand. Although we are unsure about the length of the period over which N is produced, it is clear from our work that sand-

covered cyanobacteria produce nitrogen during droughts. We hypothesise that areas inundated by sand become focal point from which cyanobacteria can recolonise the soil after droughts, and predict that this mineralisable N, when coupled with abundant soil moisture post-drought, would meet threshold requirements for germinating seeds.

In these results, the association of mineralisable nitrogen with cyanobacteria-dominated soil crusts and the accumulation under a superficial layer of sand appears crucially important in the drought-recovery cycle. It is well-known that stock trampling damages these soil crusts, significantly impacting surface stability. However, our work suggests that their ability to fix nitrogen is also compromised (Williams, unpublished data). At this point we recommend grazing management may be configured to enhance the survival of N fixing cyanobacteria thus aiding native pastures growth cycles. It is therefore imperative that more detailed examination of these processes under seasonal cycles and in different landscapes are researched further.

ACKNOWLEDGEMENTS

We thank David Tongway for guiding us through the nitrogen analyses and for his enthusiasm and patience in answering our many and varied questions. We also thank G. Dundson for his ongoing commitment by providing us with an excellent research site at Glencoban paddock.

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