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Evidence for temperature limitation of nitrogen mineralisation in the Drakensberg Alpine Centre

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ABSTRACT

We made use of pot experiments and soil mineralisation assays to test the effect of temperature on the soil nitrogen (N) economy of the Drakensberg Alpine Centre ('mountain site'). The approach was enhanced by the inclusion of a contrasting warm, subtropical environment on the east coast of southern Africa ('coast site') which presented an opportunity to test plant growth in mountain soil outside of the mountain site's natural climatic envelope. This study was further augmented by two greenhouse experiments that helped isolate the factors responsible for the growth responses in the experiments above. Plant morphology, plant nutrients and soil nutrients were used as the basis for comparing treatment effects. The primary pot experiment showed that plant growth was uniform in the mountain site regardless of whether the test species was grown in intrinsically N-rich mountain soil or intrinsically N-poor coast soil. However, we noted significant growth differences at the coast site using the aforementioned soil nutrient regimes. In terms of the soil mineralisation assay, coast soil, derived from intrinsically N-poor sandstone, predictably mineralised little soil inorganic N at the mean spring temperature of 19 °C. However against expectations, the intrinsically N-rich mountain soil mineralised <1% of its total soil N budget into inorganic N at 12 °C, most probably because the microbes responsible for the conversion of organic soil N to inorganic soil N were severely inhibited at this mean spring temperature. However, the potential to mineralise far more N in mountain soil was apparent when using an elevated experimental temperature of 30 °C, with 369% more soil N being available under the latter regime. Our results suggest that the cooler temperatures associated with high elevations in the mountain site constrain the activity of soil microbes in mountain soil, resulting in a functionally N-poor soil economy particularly deficient in inorganic N. This also explains the similar growth responses regardless of the soil being intrinsically N-rich or N-poor. We speculate whether or not more soil inorganic N may become available under a regime of warming due to accelerated N mineralisation, to the detriment of plant taxa adapted to low soil N availability.

1. Introduction

Empirical plant ecological studies are increasingly testing the limitations of membership in plant communities. Numerous studies have shown that factors such as soil nutrients and climate are key drivers exerting strong selective influences on plant traits and community composition (Grime, 1979; Kruckeberg, 1986; Tilman, 1988; Counts, 1993; Chapin et al., 1995; Ellery et al., 1995; Fynn and O'Connor, 2005).

The broad aim of this study was to test soil nutrient and climate drivers in an interactive way at the soil-climate interface through the use of pot experiments and soil mineralisation assays. More specifically we tested the temperature aspect of the climatic envelope (the latter defined as the collective influence of prevailing meteorological conditions) on the soil nitrogen (N) economy in the Drakensberg Alpine Centre of plant endemism ('mountain site'; ≥1800 m–3482 m a.s.l.), the only alpine region in southern Africa (Linder, 1990). The intrinsically N-rich soils of the mountain site's alpine and sub-alpine reaches (c. 2000 m–3482 m a.s.l.) are derived from dramatic outpourings of lava (flood basalts of the Drakensberg Formation) some 183 million years ago in the Jurassic Period (Whitmore et al., 1999; McCarthy and Rubidge, 2005). We questioned whether or not the intrinsically fertile total soil N economy of the mountain site is sovereign, or is total soil N fertility arrested by environmental factors and rendered functionally N-limited? Is temperature having a significant effect on the supply of inorganic N, particularly on the rate of N mineralisation? Given that the mountain site is a high-altitude environment, we hypothesized that the cooler temperatures associated with high elevations have constrained the activity of soil microbes, thereby resulting in a N-limited soil economy particularly deficient in available inorganic N.

Our study was enhanced by making use of an additional study area (and its native soil form), namely the Pondoland Centre of plant

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endemism (‘coast site’) located on the coastal hinterland of eastern South Africa (Fig. 1), as this region represents a contrasting set of climatic drivers (warm, subtropical, coastal) and is further constrained by intrinsically nutrient-poor soils derived from sandstones of the Msikaba Formation (Van Wyk and Smith, 2001). The coast site therefore presented an opportunity to test plant growth in mountain soil outside of the mountain site's natural climatic envelope (unconstrained by the effects of altitude). Would the test subject grown in mountain soil display uniform growth across the two contrasting sites? If not, how would this growth pattern differ and what would this result tell us about mountain soil and the mountain environment?

2. Materials and methods

This study made use of both primary and secondary experiments. The primary experiments incorporated growth trials in the two study regions. In anticipation of the potential for plant growth in mountain soil outside of the mountain site to be uncharacteristic, we set up two secondary growth trials to ascertain the cause(s) of such atypical growth responses in the primary experiments. All experiments are further detailed below.

2.1. Study sites for primary experiment

The primary experiment made use of pot experiments established in the mountain site and coast site. The mountain site was located at Garden Castle in the southern KwaZulu-Natal Drakensberg (Fig. 1) and the coast site was located at Umtamvuna (Fig. 1). The pot experiment at each site therefore comprised four site-soil combinations, namely mountain site-mountain soil; mountain site-coast soil; coast site-coast soil and coast site-mountain soil. These dynamics therefore predisposed the study to pot experiments and not transplant experiments. The pot experiments were monitored by on-site assistants to ensure that the pots remained suitably moist, and free of weeds and herbivory.

2.2. Weather conditions at study sites for primary experiment

Calibrated HOBO®-H8 data loggers (Onset Computer Corporation, Massachusetts, US) recorded temperature and relative humidity (RH) at hourly intervals at each site. Rainfall was recorded daily at each site using a standard rain gauge. The mountain site was the coolest and wettest of the two study sites, while the coast site was the most humid (Table 1). Both sites experienced very high rainfall, associated with consistently cloudy weather over the entire growth trial, which ensured that the plants were sufficiently moist throughout the trial (as confirmed by assistants assigned to oversee the experiments in their respective environments). No drought conditions were therefore experienced.

2.3. Soil forms and soil analyses for primary experiment

Topsoils from the mountain and coast sites were collected to a depth of c. 25 cm from pristine areas. These soils were used both for the pot experiments and for testing of soil nutrient status. We argue that these test soils were entirely representative because they were derived from homogenous geological sequences relevant to our study sites; soil data from other locations spread across our study regions corroborate this view (Clinton Carbutt and Trevor Edwards, unpublished data). Soils were then air-dried at room temperature, sieved through a 2 mm sieve and stored briefly in open sacks in a dry laboratory as the experiments began soon thereafter. Samples used for chemical analysis were crushed between rubber belts in a soil crusher and passed through a 1 mm sieve. Total carbon (C) and N were determined by Dumas dry combustion. Available soil N was determined twice, firstly from non-incubated soils and secondly from incubated soils after mineralisation. N (NH_4^+) and N (NO_3^-) concentrations were determined from five replicates of 20 g air-dried soil extracted in 50 ml 2 *M* KCl (Bremner, 1965). Samples were shaken for two hours, filtered and analysed in a Bran + Luebbe TRAACS 2000 continuous-flow automated analyzer. Mineralisable N was determined after ten days of closed aerobic incubation with soils moistened to field capacity in sealed Erlenmeyer flasks.

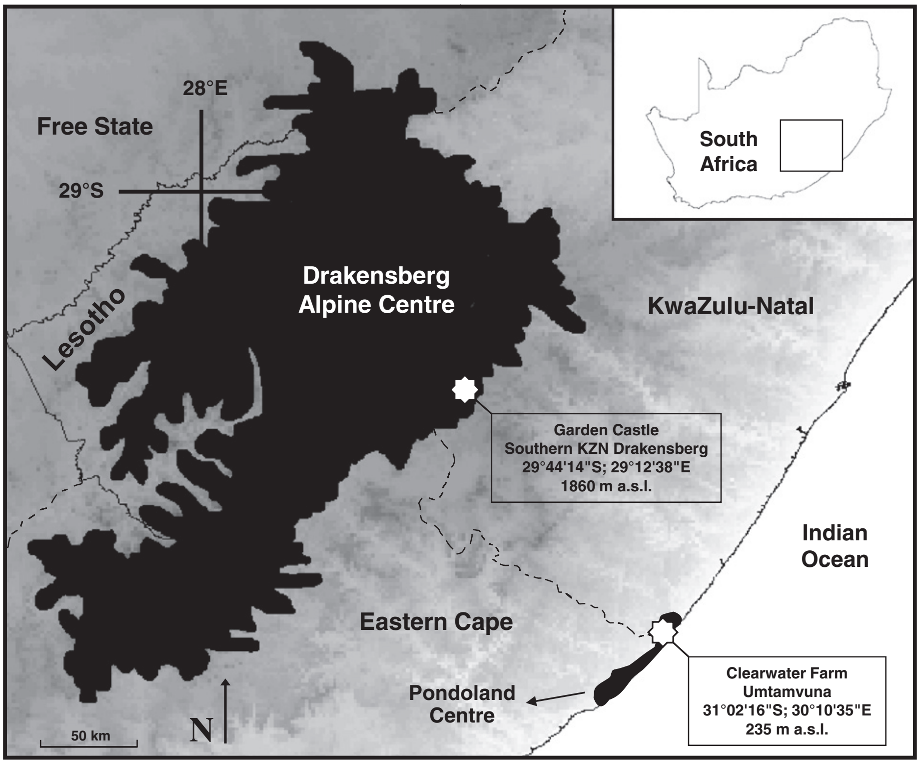

Fig. 1. The two study sites accommodating the *Diascia mollis* pot experiments in KwaZulu-Natal, South Africa. Site coordinates and altitudes were generated with a Global Positioning System (GPS).