

## Short Communication

## Diverse responses of belowground internal nitrogen cycling to increasing aridity



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## ARTICLE INFO

## Keywords:

Ammonia oxidation archaea  
Drylands  
Mineralization  
Microbial immobilization  
Nitrification  
Nitrogen cycle

## ABSTRACT

Belowground microbial nitrogen (N) processes play key roles in regulating terrestrial ecosystem services such as vegetation production, however, our understanding of their responses to climate change remains limited. We determined patterns and controls of five gross N transformation processes along a typical aridity gradient on the Tibetan Plateau. Potential gross N transformation rates responded diversely to the changing aridity. Both mineralization ( $M_N$ , average rate:  $2.87 \text{ mg N kg}^{-1} \text{ soil d}^{-1}$ ) and ammonium immobilization ( $I_{NH_4}$ ,  $3.35 \text{ mg N kg}^{-1} \text{ soil d}^{-1}$ ) declined as aridity increased. Autotrophic nitrification ( $O_{NH_4}$ ,  $1.72 \text{ mg N kg}^{-1} \text{ soil d}^{-1}$ ) exhibited a bell-shaped pattern along the gradient, with an optimum aridity of 0.53 (1- aridity index (AI)). By contrast, rates of nitrate immobilization ( $I_{NO_3}$ ,  $0.46 \text{ mg N kg}^{-1} \text{ soil d}^{-1}$ ) and dissimilatory nitrate reduction to ammonium (DNRA,  $0.10 \text{ mg N kg}^{-1} \text{ soil d}^{-1}$ ) did not respond to the changing aridity. These results suggest that predicted increases in aridity will exert different effects on various soil internal N cycling processes, and thus potentially have profound impact on structure and function of dryland ecosystems.

Drylands, the largest terrestrial biome and one of the most sensitive ecosystems to environmental changes, provide crucial ecosystem services (e.g., food and fibre production, carbon sequestration) for more than 38% of the global population (Maestre et al., 2012; Schimel, 2010). Although primarily limited by water availability, ecosystem services in drylands are secondarily limited by nitrogen (N) availability (Delgado-Baquerizo et al., 2016). Therefore, ecosystem N cycling as a function of aridity, the major climate driver in drylands, has attracted increasing interest. However, previous studies focused mainly on the effect of changing aridity on state variables related to N cycling (e.g., total N (TN), available N and  $\delta^{15}\text{N}$ ; Delgado-Baquerizo et al., 2013a, 2016; Wang et al., 2014), with notably less attention paid on belowground gross N transformations. Given that biogeochemical N cycling and the availability of N in the biosphere are governed by a series of simultaneously occurring N transformation processes (Booth et al., 2005; Chapin et al., 2011), it is essential to reveal patterns and controls of belowground microbial N processes along aridity gradients in drylands.

To examine the potential responses of soil microbial N processes to

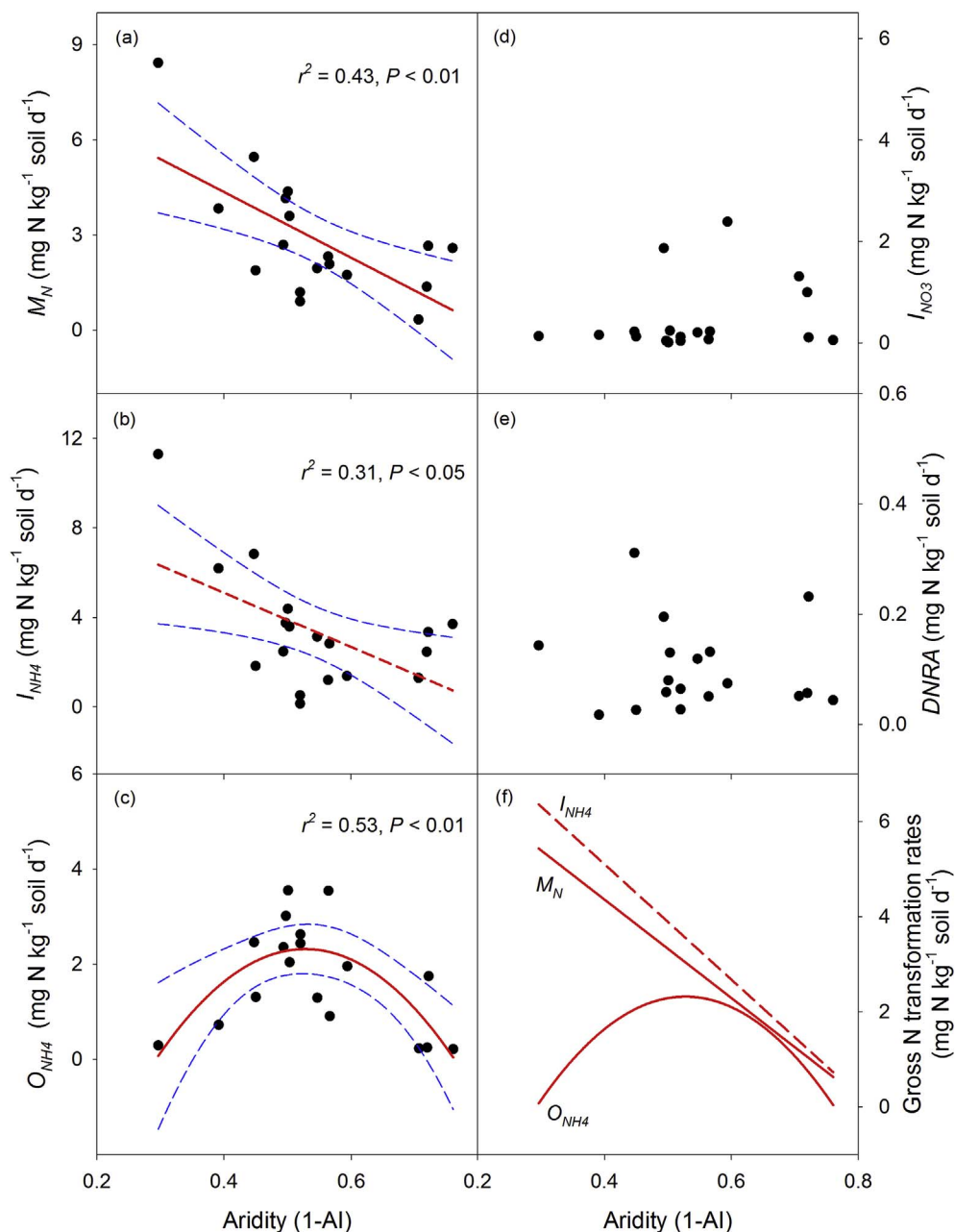
aridity, we collected surface soil (0–10 cm) samples from 18 sites along an aridity gradient on the Tibetan Plateau during the summer (July and August) of 2014 (Table S1). With those soil samples, we quantified a set of simultaneously occurring gross N transformation rates using a  $^{15}\text{N}$ -tracing technique and also determined a suite of physical and chemical properties and microbial characteristics, including phospholipid fatty acids (PLFA) and *amoA* gene abundance of ammonia oxidizing archaea (AOA) and bacteria (AOB). In addition, the aridity index (AI, the ratio of precipitation to potential evapotranspiration) was extracted from the CGIAR-CSI Global-Aridity and Global-PET database (<http://www.cgiar-csi.org>) (Zorner et al., 2008). The relative importance of biotic and abiotic variable on gross N transformation rates was assessed using a multi-model inference approach (Maestre et al., 2012). See more details in the supplementary materials.

Our results showed that gross N transformation rates, including gross N mineralization ( $M_N$ ), ammonium ( $\text{NH}_4^+$ ) immobilization ( $I_{NH_4}$ ), autotrophic nitrification ( $O_{NH_4}$ ), nitrate ( $\text{NO}_3^-$ ) immobilization ( $I_{NO_3}$ ) and dissimilatory nitrate reduction to ammonium (DNRA), exhibited large spatial variability on the Tibetan Plateau (Fig. 1 and Fig. S1).

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**Fig. 1.** Variations of soil microbial gross N transformation rates along a typical aridity gradient on the Tibetan Plateau. a,  $M_N$ , gross N mineralization; b,  $I_{NH_4}$ , immobilization of  $NH_4^+$ ; c,  $O_{NH_4}$ , autotrophic nitrification;  $I_{NO_3}$ , immobilization of  $NO_3^-$ ; d, DNRA, dissimilatory  $NO_3^-$  reduction to  $NH_4^+$ . To facilitate the explanation of our results, aridity is defined as 1-AI, where AI (aridity index) is the ratio of precipitation to evapotranspiration. The red lines and blue dashed lines represent the fitted curves and their 95% confidence intervals, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Among these rates, both  $M_N$  and  $I_{NH_4}$  were negatively correlated with aridity (1-AI) ( $M_N$ :  $P < 0.01$ ;  $I_{NH_4}$ :  $P < 0.05$ ; Fig. 1a-b). Consistent with the decrease of  $M_N$  and  $I_{NH_4}$  along the aridity gradient, our results revealed that factors that tend to promote the rates of  $M_N$  and  $I_{NH_4}$ , such as plant cover, clay content, soil organic matter, available substrate (dissolved organic N (DON) for  $M_N$ ;  $NH_4^+$  for  $I_{NH_4}$ ) and total microbial biomass, declined with increasing aridity, whereas variables such as pH that tend to inhibit  $M_N$  and  $I_{NH_4}$  increased with aggravated drought (Figs. S2-3, S5). These results suggested that the interaction of vegetation, soil environment, substrate and microbial community along the aridity gradient caused the decreases in rates of  $M_N$  and  $I_{NH_4}$  with the increasing aridity. Among all factors, available substrate was the most important in regulating the variations in rates of both  $M_N$  and  $I_{NH_4}$  (Fig. 2a-b, Table S2). Moreover, neither  $M_N$  nor  $I_{NH_4}$  exhibited any significant relationships with soil SOC:TN, F:B or G+:G-ratio (Figs. S2-3), suggesting that substrate quality and microbial community composition were not the significant drivers for  $M_N$  and  $I_{NH_4}$  along this aridity gradient.

Autotrophic nitrification exhibited a bell-shaped pattern along the aridity gradient, with the maximum rate occurring at aridity (1-AI) = 0.53 ( $P < 0.01$ ; Fig. 1c). Such a relationship could be explained by the similar pattern of ammonia supplying capacity (reflected by  $M_N - I_{NH_4}$ , the difference between  $M_N$  and  $I_{NH_4}$ ) and the abundance of AOA along the aridity gradient (Fig. S5k-l), which was further demonstrated by the significant linear association between  $O_{NH_4}$  and  $M_N - I_{NH_4}$  or AOA (Figs. S4g-h) and the large importance values of  $M_N - I_{NH_4}$  and AOA (Fig. 2c, Table S2). A question then is why  $M_N - I_{NH_4}$  and AOA exhibited bell-shaped patterns along the aridity gradient. Before approaching the optimum aridity (aridity (1-AI) = 0.53, i.e., the relatively wet region), we expected that the increase in ammonia supplying capacity and AOA abundance that occurred with increasing aridity could be largely due to decreased competition of heterotrophic microorganisms as well as plants for ammonium against nitrifiers (Chapin et al., 2011; Delgado-Baquerizo et al., 2013b). However, the decline in ammonia supplying capacity and AOA abundance after reaching the optimum aridity (aridity (1-AI) = 0.53, i.e., the relatively dry region) might be attributed to

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