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# Afforestation with xerophytic shrubs accelerates soil net nitrogen nitrification and mineralization in the Tengger Desert, Northern China

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ABSTRACT

Afforestation with xerophytic shrubs in drylands to curb desertification and land degradation has been increasingly implemented worldwide. However, the effects of this restoration practice on soil nitrogen mineralization and availability in desert areas remain poorly understood. We investigated the seasonal patterns of soil inorganic N pools and net N nitrification and mineralization in mobile sand dune and three shurblands (afforested in 1956, 1964 and 1981, respectively) in the Tengger Desert by using the *in situ* incubation method. Our results showed that afforestation significantly increased the soil inorganic N pools, and net nitrification and mineralization rates. Annual average values of $NH_4^+$-N, $NO_3^-$-N and total inorganic N were 2.64–4.06, 3.37–7.74 and 3.06–6.12 times greater in afforested sites that those in mobile sand dunes, with $NO_3^-$-N being predominated in all sites and its proportion being increased with stand age. In mobile sand dune, annual soil net N nitrification and mineralization rates were 1.25 and 1.87 mg N $m^{-2}$ $d^{-1}$, respectively, while those in afforested sites were 5.32–11.89 and 5.98–15.16 times higher, respectively, with nitrification predominated the N mineralization process. Marked seasonality in inorganic N pools, net N nitrification and mineralization were observed with the highest values in summer and the lowest in winter, which were closely linked to afforestation-induced changes in soil temperature and moisture as well as surface litter, content of clay and silt, C: N and OC of soil. The contrasting results for soil N transformations were observed during non-growing season, that was net N immobilization for the mobile sand dune without afforestation and the shrubland established in 1981, while net N mineralization for the shrublands established in 1964 and 1956, the latter two sites account for 2.65% and 9.68% of their total mineralization, respectively. These results suggested that afforestation with xerophytic shrubs has positive effects on soil nitrogen availability and cycling in desert region. It also implied that the afforestation-triggered recovery of biogeochemical cycling of N was a long-term process, and therefore soil habitat conservation is a vital issue in desert ecosystems.

## 1. Introduction

Soil nitrogen (N) availability is a key factor influencing plant growth in drylands where N is the first limiting nutrient (Robertson and Groffman, 2007; Schlesinger and Bernhardt, 2013; Delgado-Baquerizo et al., 2014). However, N availability is actually determined by net N mineralization which transforms organic N to inorganic N from soil organic matter (SOM) by soil microorganisms (Chapin III et al., 2011; Liu et al., 2017a), therefore, any modification that influences N mineralization will directly affect N availability and primary productivity in drylands (Schimel and Bennett, 2004; Schlesinger and Bernhardt, 2013), and thus impact ecosystem functioning and long-term resilience (Heitkamp et al., 2008; Chen et al., 2009; Schlesinger and Bernhardt, 2013).

Covering about one-third of the Earth's land surface, arid and semi-arid regions serve as the largest biome type in the world (Reynolds et al., 2007; Delgado-Baquerizo et al., 2014). However, most of these regions have undergone degradation and desertification due to climate change and improper land use and management (Nosetto et al., 2006; Li et al., 2016). Ecological restoration through afforestation is a common and effective method to combat desertification in many arid regions of the world (Lal, 2004; Li et al., 2007; Li et al., 2016). Globally, this restoration practice has been found to increase vegetation cover, primary productivity and SOM accumulation in drylands (Guo and

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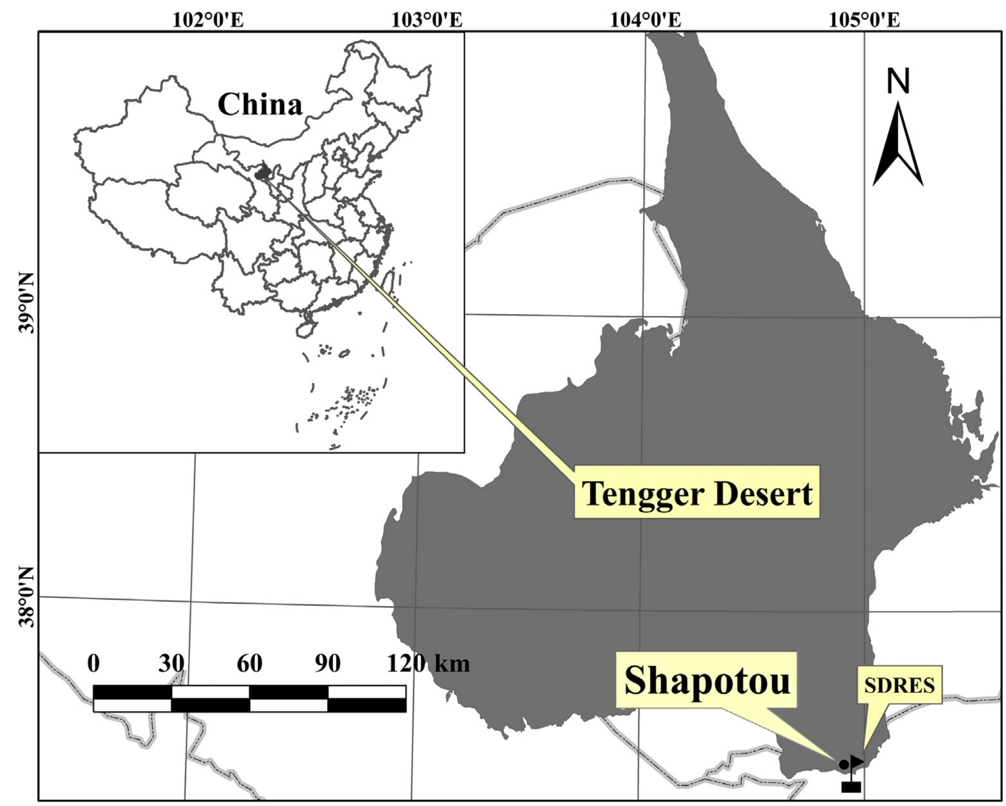


**Fig. 1.** Location of the study site at Shapotou in the Tengger Desert, northern China. SDRES represents the Shapotou Desert Research and Experiment Station, Chinese Academy of Sciences.

Gifford, 2002; Ford et al., 2007; Reynolds et al., 2007; Yang et al., 2014). Greater SOM inputs and vegetation cover may potentially improve soil microenvironments and soil microbial communities, and thereby stimulate SOM decomposition and soil N mineralization (Ford et al., 2007; Zeng et al., 2009; Huang et al., 2015), which in turn will affect long-term productivity, ecosystem function and the sustainability of these artificial ecosystems (Schlesinger and Bernhardt, 2013; Tapia-Torres et al., 2015; Li et al., 2016). Therefore, determination of soil N transformation rates and the controlling factors has long been the interest of ecologists as they seek to understand the controls on productivity and functions of restored ecosystems (Schimel and Bennett, 2004; Booth et al., 2005).

In last decades, although the effects of afforestation on soil N mineralization have been extensively studied, most of the previous research focused on the effects of land use change (Zhang et al., 2008; Contosta et al., 2011; Li et al., 2014), and divergent results have resulted in a lack of consensus about the direction and magnitude of N transformations after afforestation (Li et al., 2014). For example, increase (e.g., Gürlevik and Karatepe, 2016; Wang et al., 2017), decrease (e.g., Yang et al., 2010; Li et al., 2014) as well as insignificant change (e.g., Zeng et al., 2009) of soil N mineralization have been reported. These discrepancies might arise from variations in climate, vegetation type and land-use history (Burke, 1989; Zeng et al., 2009; Li et al., 2014). Recently, restoration of some ecosystem services after afforestation in desert ecosystems has gained importance, such as plant productivity, vegetation cover and soil physical, chemical and microbial properties (Guo and Gifford, 2002; Lal, 2004; Nosetto et al., 2006; Li et al., 2007; Yang et al., 2014; Li et al., 2016). However, relatively few attentions have been paid to soil N transformations during the process of artificial vegetation restoration in these regions (Wang et al., 2017), especially in the areas characterized by mobile sand dunes. As such, the dynamics and controls on N availability in afforested sand dune remain poorly understood. Furthermore, as a microbial-mediated process, the dynamics of soil N transformations are often controlled by several factors, such as soil temperature and moisture, soil texture and pH (Burke, 1989; Zhou et al., 2009; Wang et al., 2010; Chapin III et al., 2011; Li et al., 2014). However, the response of different ecosystems to these factors vary (Booth et al., 2005; Zhou et al., 2009; Chapin III et al., 2011), which necessitate the site-specific evaluation of N transformations (Burke, 1989; Liu et al., 2017a).

Since the early 1950s, planting xerophytic shrubs on shifting sand dunes has become the widely used option to rehabilitate degraded land in arid and semiarid regions of China (Nosetto et al., 2006; Li et al., 2007; Li et al., 2016). In order to protect the Lanzhou-Baotou railway from sand burying, vegetation protection system with straw checkerboards and sand-binding shrublands was established on sand dunes at the southeast fringe of the Tengger Desert in 1956, followed by further planting in 1964 and 1981 (Li et al., 2007). It is well recognized that the established shrublands have resulted in significant enhancements in plant cover and biomass and SOM accumulation (e.g., Li et al., 2007; Yang et al., 2014; Li et al., 2016), and soil physicochemical and microbial properties (e.g., Li et al., 2007; Li et al., 2016; Jia et al., 2017; Liu et al., 2017b). However, little is known about how introduced shrubs to sand dunes affecting soil N transformations. Therefore, in this study, *in situ* incubation experiments were conducted to investigate soil inorganic N contents, net N nitrification and mineralization rates over different seasons through a chronosequence sampling in the Tengger Desert, and soil properties and environmental factors were also measured. The objectives of this research are to (1) determine whether shrub plantation in desert ecosystem could stimulate soil N transformations; (2) identify the key biotic and abiotic factors that control soil N dynamics in restored ecosystem. A further purpose of this study is to contribute to an understanding of the mechanisms involved in soil N transformations following shrub planting in desert regions.