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The effect of nitrogen addition on community structure and productivity in grasslands: A meta-analysis

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ABSTRACT

The ongoing increase in anthropogenic nitrogen (N) addition may have a substantial impact on grassland ecosystems. Understanding the dynamics of the productivity and community structure of grassland ecosystems following N addition is important. We conducted a meta-analysis of the data from 2516 quadrats described in 56 published N-addition studies and aimed to address these questions and further describe the productivity and community structure of grassland ecosystems in response to N addition in China. Our results showed the critical threshold for N-induced productivity loss to grassland was variable. In meadow steppe, when the range of N addition occurred at rates between 7.5 and 20 g N m^{-2} yr^{-1}, the aboveground net primary production (ANPP) increased, and below this range, the biomass of the functional groups (forb, grass, and sedge) decreased. Furthermore, above the range, both productivity and structure were negatively related to the rate of N addition. The critical threshold for the N-induced changes in the productivity of the desert steppe was 10.5 g N m^{-2} yr^{-1}, at which production increases with no reduction in diversity. Additionally, the increase in ANPP with N addition stabilizes above approximately 12 g N m^{-2} yr^{-1} in desert steppe, and the decrease in species richness with N addition stabilizes above approximately 11 g N m^{-2} yr^{-1}. Thus, at approximately 11 g N m-2 yr^{-1}, further N addition causes no increase in production and a clear reduction in diversity. Our results contribute to a better understanding of the consequences of future climate change in grassland ecosystems.

1. Introduction

Atmospheric nitrogen (N) addition continues to increase in terrestrial ecosystems (Matson et al., 2002; Galloway et al., 2004; Liu et al., 2013). The annual input of anthropogenic reactive N has increased more than 10-fold in the last 150 years, and N atmospheric addition rates are predicted to increase another two- to three-fold in the coming years (Galloway and Cowling, 2002). The impact of this unprecedented anthropogenic N addition on the global N cycle has exceeded the levels recommended to ensure the resilience of the ecosystem functions and processes of Earth, especially when input rates are large and continuous (Rockström et al., 2009; Stevens et al., 2015). N addition alters fundamental processes, such as biodiversity, climate regulation, carbon cycling and biogeochemical cycles (Matson et al., 2002; Stevens et al., 2004; Clark and Tilman 2008; Sutton et al., 2011), and causes soil acidification, which leads to further impacts on soil base cations, the soil cation exchange capacity and base saturation percentages (Lu et al., 2014).

Grasslands are one of the most important terrestrial ecosystems and play important roles in maintaining terrestrial ecosystem functions and processes (Van Den Berg et al., 2011). N is a limiting nutrient for plant growth and strongly defines the patterns of plant growth and allocation in grassland ecosystems, where N additions cause an increase in net primary production (NPP) (Bai et al., 2010; Van Den Berg et al., 2011). Stevens et al. (2015) used an international multiscale dataset to show that atmospheric N addition was positively correlated with aboveground net primary production (ANPP) and was a better predictor than climatic drivers. The authors explained that 16% of the observed variation in the global ANPP is attributable to N addition because an increase of 1 kg N ha^{-1} yr^{-1} can increase ANPP by 3% across a wide range of herbaceous ecosystems. However, Wang et al. (2010) found that N fertilization had no significant effect on NPP in an alpine meadow.

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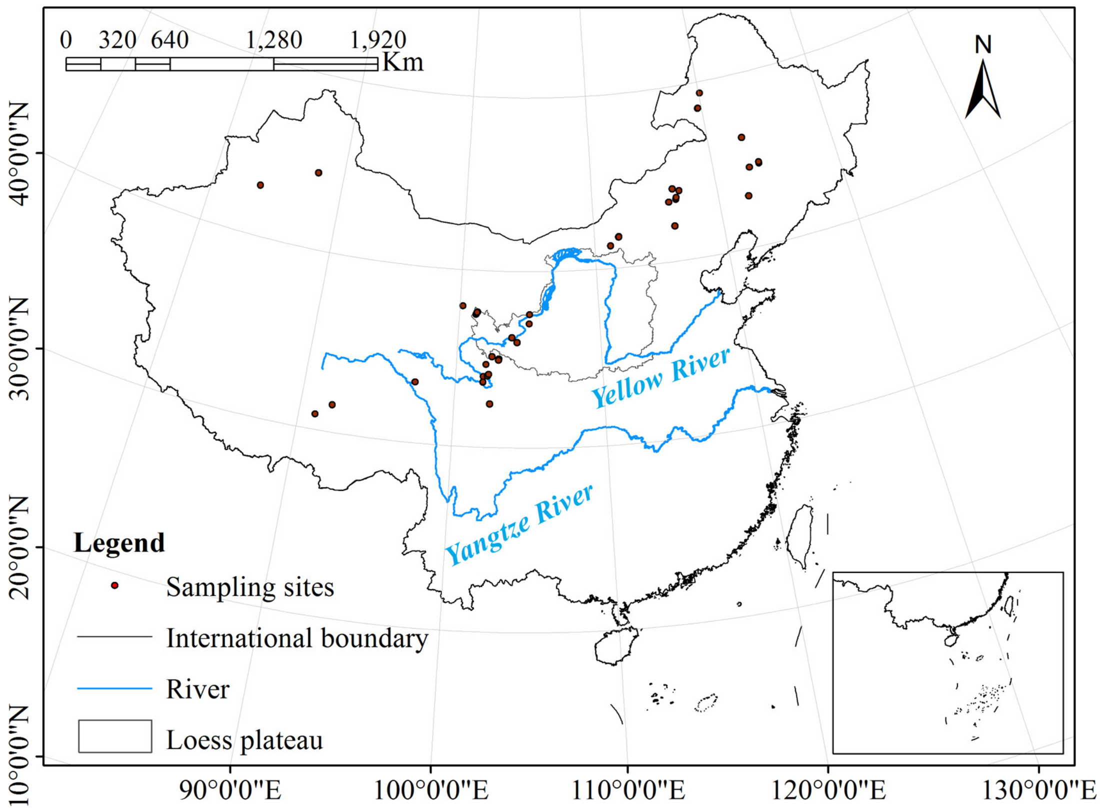

Fig. 1. Location of the study area. The pictures were generated by ArcMap version 10.2 (http://www.esri.com/).

In addition, the vegetation community is one of the critical factors that maintains balance in the structure and function of an ecosystem (Sala et al., 2000; Johnson et al., 2015; Mouquet et al., 2015). In many systems, however, this component is being fundamentally altered by anthropogenic atmospheric N addition (Stevens et al., 2004; Payne et al., 2013). Numerous N addition experiments in different ecosystems have shown that N addition affects community structure. For example, Stevens et al. (2004) found that N addition decreased species richness in a national survey of an acidic grassland community in the United Kingdom. Carroll et al. (2003) and Van Den Berg et al. (2011) reported that N addition had no significant spatial association with species richness and species diversity, both of which adapted to low-nutrient conditions. However, experimental long-term N addition changed the species composition and significantly decreased the species diversity and the Pielou index. Furthermore, under high rates of N addition, the changing species composition led to a reduction in the forb/grass ratio. Bai et al. (2010) observed that N addition reduced species richness and changed species composition; simultaneously, these authors found that mature grassland in Inner Mongolia was very sensitive to N-induced changes in community structure. Recent studies of N addition have mainly been based on N addition experiments, which are valuable for identifying cause–effect relationships that help us understand the changes in the functions and processes of grassland ecosystems undergoing atmospheric N addition, but these experiments have limitations. Recent critical load experiments have focused on single ecosystems in local sites. As a result, these studies are poorly suited for use in identifying information regarding the large-scale environmental impacts of N addition in different ecosystems. An understanding of the effects of atmospheric N addition on grassland ecosystems is essential for evaluations of ecological effects, e.g., plant diversity and productivity. Furthermore, an understanding of the relationships between grassland productivity and community structure is necessary for the long-term sustainable management of grassland ecosystems undergoing atmospheric N addition.

Therefore, a meta-analysis was conducted based on 14 variables related to productivity and community structure in different grassland ecosystems from 56 experimental studies in China. The aim of this meta-analysis was to use a dataset to address unresolved questions and to increase the available knowledge regarding the responses of grassland ecosystems to N addition. Furthermore, the following concerns are addressed: (1) the response of productivity and community structure to N addition and different N levels present in different grassland ecosystems and (2) the relationship between productivity and community structure in grasslands exposed to N addition. Our results contribute to a better understanding of the consequences of future climate change in grassland ecosystems and will help inform the effective management of grasslands to support long-term ecosystem functions and services.

2. Methods

2.1. Data collection

In this meta-analysis, data were collected from 2516 quadrats described in 56 (S1) peer-reviewed journal articles, including 31 study sites (Fig. 1) and three different grassland ecosystems (desert, meadow, and typical steppe). The search terms were (nitrogen/N/fertilizer) AND (productivity/community structure) in Web of Science, Google Scholar, and CNJD (China Academic Journal Network Publishing Database). The criteria described below were adopted to enable the selection of appropriate studies and to avoid bias in publication selection. (1) Experiments were conducted using at least one pair of datasets (under control and treatment), including N addition rates, species richness, community coverage, average height, Margalef index, Shannon-Wiener index, Simpson index, Pielou index, density, ANPP, litter biomass,