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The composition, spatial patterns, and influencing factors of atmospheric wet nitrogen deposition in Chinese terrestrial ecosystems

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HIGHLIGHTS

- Atmospheric N deposition impacts terrestrial ecosystems.
- Composition of wet N deposition in China scale was first reported.
- Atmospheric N deposition was underestimated without particulate N in rainfall.
- Precipitation, N fertilizer use, and energy consumption influence wet N deposition.

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ABSTRACT

Atmospheric nitrogen (N) deposition is an important component of the global N cycle, and is a key source of biologically available N. Understanding the spatio-temporal patterns and influencing factors of N deposition is essential to evaluate its ecological effects on terrestrial ecosystems, and to provide a scientific basis for global change research. In this study, we monitored the monthly atmospheric N deposition in rainfall at 41 stations from the Chinese Ecosystem Research Network through measuring total N (TN), total dissolved N (TDN), ammonium (NH_4^+–N), and nitrate (NO_3^-–N). The results showed that the atmospheric wet deposition of TDN, NH_4^+–N, and NO_3^-–N were 13.69, 7.25, and 5.93 kg N ha^{-1} yr^{-1}, respectively. The deposition of TN and total particulate N (TPN) was 18.02 and 4.33 kg N ha^{-1} yr^{-1} respectively, in 2013. TPN accounted for 24% of TN, while NH_4^+–N and NO_3^-–N made up 40% and 33%, respectively, confirming the assumption that atmospheric wet N deposition would be underestimated without particulate N in rainfall. The N deposition was higher in Central and Southern China, and lower in North-west, North-east, Inner Mongolia, and Qinghai–Tibet regions. Precipitation, N fertilizer use, and energy consumption were significantly correlated with wet N deposition (all $p < 0.01$). Models that included precipitation and N fertilizer can explain 80–91% of the variability in wet N deposition. Our findings reveal, for the first time, the composition of the wet N deposition in China at different scales and highlight the importance of TPN.

1. Introduction

The deposition of atmospheric nitrogen (N) is integral to the global N cycle (Galloway et al., 2004; Liu et al., 2011). Anthropogenic activities over recent decades, such as the burning of fossil fuels and fertilizer application, resulted in a rapid increase in the emission of reactive N (Neff et al., 2002). It was estimated that the production of reactive N increased from 15 Tg N in 1860 to 156 Tg N in 1995, with a further increase up to 187 Tg N in 2005 (Galloway et al., 2008). On the one hand, atmospheric N deposition has a positive effect on maintaining plant productivity of terrestrial ecosystems through enhancing the N availability (Fleischer et al., 2013; Reay et al., 2008; Thomas et al., 2010; Ti et al., 2012); on the other hand, excessive N deposition has negative impacts on ecosystem health and services, such as N saturation (Aber et al., 1989; Kopacek et al., 2013), soil acidification (Bowman et al., 2008; Maljanen et al., 2013; Vitousek et al., 1997), and loss of biodiversity (Bobbink et al., 2010; Stevens et al., 2004).

Observations of atmospheric N deposition are essential for evaluating its ecological effects on terrestrial ecosystems (Galloway et al., 2008; Liu et al., 2011, 2013). Some studies have reported the observed results of atmospheric N deposition at a local scale (Chen and Mulder, 2007; Huang et al., 2013), from catchments (Chen et al., 2011; Yu et al., 2011), or from belt transects (Sheng et al., 2013; Zhan et al., 2014) in China. Data collection, meta-analysis, and models have been used to estimate regional N deposition in China (Lü and Tian, 2007; Jia

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et al., 2014). However, there is currently no representative national scale observation network for atmospheric N deposition in China. Therefore, it is difficult to compare or evaluate these findings because of the higher uncertainty caused by different sampling and analytical methods. Furthermore, no study has evaluated particulate N in wet deposition in China, although the fluxes of dissolved wet N deposition (NH_4^+–N and NO_3^-–N) have been reported (Zhang et al., 2006; Huang et al., 2013; Shen et al., 2013). As a potential N source, ignoring particulate N deposition in rainfall would underestimate the N input through rainfall in terrestrial ecosystems.

In this study, we selected 41 stations from the Chinese Ecosystem Research Network (CERN) to monitor atmospheric wet N deposition through rainfall events. These stations cover the main types of terrestrial ecosystems in China (Fu et al., 2010). Precipitation was collected monthly, and total N (TN), total dissolved N (TDN), ammonium (NH_4^+–N) and nitrate (NO_3^-–N) were measured to investigate the composition, spatial patterns, and drivers of wet N deposition. The main objectives were to: 1) investigate wet N deposition in Chinese terrestrial ecosystems; 2) clarify the composition of wet N deposition; and 3) explore the main influencing factors of wet N deposition in China.

2. Methods

2.1. Site description

The 41 study sites cover the major terrestrial ecosystems in China (Table S1, Fig. 1), including forest, grassland, desert, lake, karst, and urban ecosystems (Fu et al., 2010). Based on these stations, we constructed a new observation network to monitor atmospheric wet N deposition at national scale. These stations are distributed within 22 Chinese provinces and can be divided into eight ecological regions based on climate and vegetation (Fig. 1). The observational network provides a new approach to explore the patterns of atmospheric N deposition in China from single sites, to ecological regions, and up to national scale.

2.2. Sampling and analysis

Precipitation was collected into plastic buckets installed at the height of 1.5 m above the ground at the onset of rain (or snow) in 2013. The samples were collected over the duration of rainfall, and included soluble and insoluble particulates in precipitation. Collection was conducted about 3–5 times in each month; the samples were mixed evenly to get a monthly sample, and were then stored in polyethylene plastic bottles under −20 °C.

Each sample was divided in two parts in the laboratory. One part was digested using the alkaline potassium persulfate digestion method, to measure total N (TN) of mixed rainfall in the continuous flow analyzer (FUTURA, Alliance Instruments, France). The other part was first filtered by gravity through a 0.45 μm membrane filter to remove insoluble particulates, and then the concentrations of TDN, NH_4^+–N, and NO_3^-–N were measured using the same continuous flow analyzer. The methods of duplicates, blank, and standard materials were used to control data quality.

2.3. Data calculation and analysis

The different components of wet N deposition were calculated using the following equations:

$$DIN = NH_4^+{-}N + NO_3^-{-}N \quad (1)$$

$$DON = TDN{-}DIN \quad (2)$$

$$TPN = TN{-}TDN \quad (3)$$

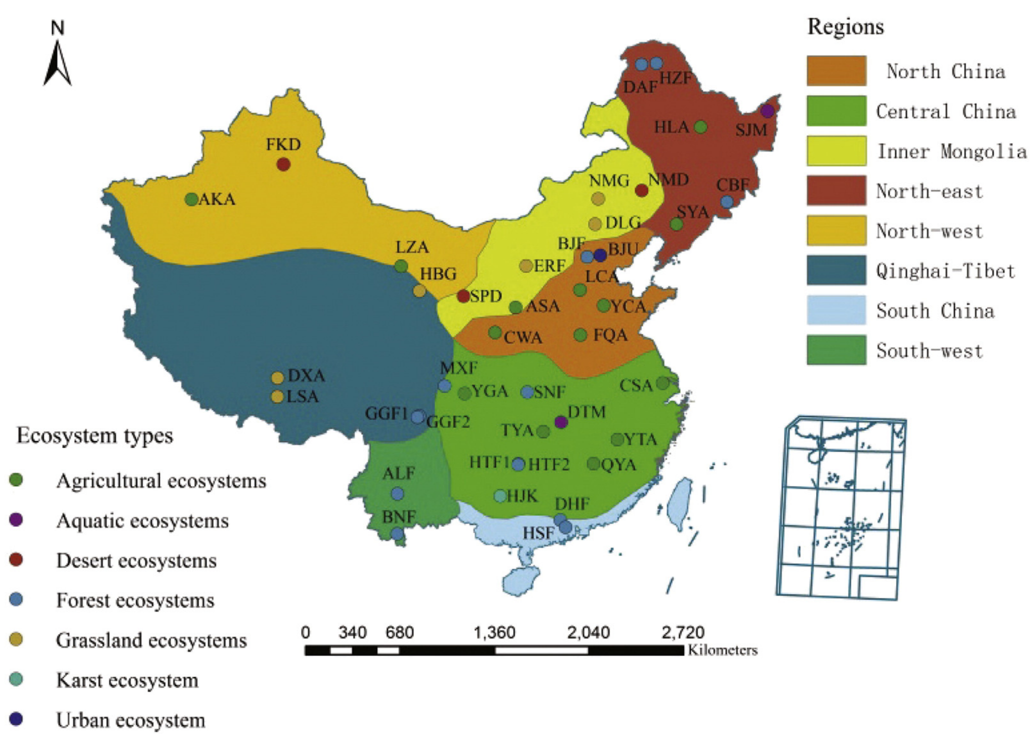

Fig. 1. The distribution of the 41 observation sites and 8 ecological regions for atmospheric wet N deposition across China. Aksu (AKA), Ailao Mountains (ALF), Ansai (ASA), Beijing (BJU), Inner Mongolia Grassland (NMG), Changshu (CSA), GreaterKhingan (DAF), Dangxiong (DXA), Dinghu Mountain (DHF), Dongling Mountain (BJF), Dongting Lake (DTM), Duolun (DLG), Erdos (ERF), Fengqiu (FQA), Fukang (FKD), Gongga Mountain 1600 m (GGF1), Gongga Mountain 3000 m (GGF2), Haibei (HBG), Hailun (HLA), Heshan (HSF), Huzhong (HZF), Huanjiang (HJK), Huitong 1 (HTF1), Huitong 2 (HTF2), Lhasa (LSA), Linze (LZA), Luancheng (LCA), Miaoxian (MXF), NaimanCounty (NMD), Qianyanzhou (QYA), Sanjiang (SJM), Shapotou (SPD), Shennongjia (SNF), Shenyang (SYA), Taoyuan (TYA), Xishuanbanna (BNF), Yanting (YGA), Yingtan (YTA), Yucheng (YCA), Changbai Mountains (CBF), and Changwu (CWA). The dots with different colors represent different ecosystem types.