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Inorganic nitrogen wet deposition: Evidence from the North-South Transect of Eastern China

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A B S T R A C T

We examined the spatio-temporal variation of dissolved inorganic nitrogen (DIN) deposition in eight typical forest ecosystems of Eastern China for three consecutive years. DIN deposition exhibited an increasing gradient from north to south, with $N - NH_4^+$ as the predominant contributor. DIN deposition in precipitation changed after interaction with the forest canopy, and serious ecological perturbations are expected in this region. DIN deposition presented seasonal fluctuations, which might be ascribed to agricultural activity, fossil-fuel combustion and environmental factors (i.e., wind direction, soil temperature). Notably, N fertilizer use (F_N), energy consumption (E), and precipitation (P) jointly explained 84.3% of the spatial variation in DIN deposition, of which F_N (27.2%) was the most important, followed by E (24.8%), and finally P (9.3%). The findings demonstrate that DIN deposition is regulated by precipitation mainly via anthropogenic N emissions, and this analysis provides decision-makers a novel view for N pollution abatement.

1. Introduction

Atmospheric nitrogen (N) deposition has increased sharply due to the rapid increase in reactive N resulting from industrialization and intensive agricultural activities over the last century (Galloway et al., 2008). Excessive N deposition has resulted in serious environmental issues globally, including global warming (Churkina et al., 2009), loss of biodiversity (Bobbink et al., 2010), surface water acidification (Bouwman et al., 2002), and risks to human health (Richter et al., 2005).

Although forests are commonly considered to be N deficient, and there is no direct anthropogenic nitrogen input like fertilizer to unmanaged forests (Thomas et al., 2010), recent studies have confirmed that N deposition in forests has reached unprecedented levels because of anthropogenic activities, and the “N saturation” hypothesis was then brought up (Nave et al., 2009; Sutton et al., 2011). Thus, quantifying N deposition in forests has been a crucial topic in global biogeochemical research. Consequently, several research programmes have been initialed to study atmospheric N deposition in forests, such as the large-scale European NITREX (Nitrogen saturation experiment), SFONE (Swedish Forest Optimum Nutrition Experiments), and EANET (Acid deposition monitoring network in East Asia). These programmes found that “N saturation” appeared in many forests, i.e., in Poland and many parts of Europe (Fischer et al., 2007; Walna and Kurzyca, 2007). However, researches on N deposition in China have primarily focused on heavily polluted regions, and only few measurements have been conducted in forests (Fang et al., 2011; Zhao et al., 2009). Concerns

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over N deposition in Chinese forests remain in the initial stage, and little is known about the current N deposition and its drivers using observed data on the regional scale (Chen and Mulder, 2007; Yu et al., 2011).

Located in the heavily forested area, the North-South Transect of Eastern China (NSTEC) provides an ideal platform for studying dissolved inorganic N (DIN, including $N-NO_3^-$ and $N-NH_4^+$) deposition in Chinese forest ecosystems. In order to fill the gap in the knowledge of N deposition, a study in the NSTEC was undertaken. In this study, integrated DIN deposition data were measured continuously by the ion-exchange resin (IER) technique for three years, and data on wind direction, precipitation, N fertilizer use and energy consumption were used to present a more comprehensive assessment of DIN deposition in typical forest ecosystems. The primary purposes of this study were to investigate the spatio-temporal variation of DIN deposition, and the associated driving forces. The outcomes of our investigation may be of value to planners and decision-makers in their efforts to evaluate the effects of consequent N deposition on forest ecosystems and then to curb N emissions within the study region.

2. Materials and methods

2.1. Study site

The NSTEC extends from Hainan Island to China's northern border, with a spatial distance of more than 3700 km, ranging from 108° E to 118° E for latitude below 40° N and from 118° E to 128° E for latitude above 40° N (Fig. 1). Due to the influence of the East Asian monsoon, the climate of the NSTEC displays obvious latitudinal gradients for temperature and precipitation, and the great spatial variation in climate is the primary driver for the diverse distribution of forest ecosystems within the transect (Peng et al., 2002).

In order to guarantee the smooth development of our observations (such as field sampling and sample storage), only sites with staff and basic experiment facilities were chosen. Thus, eight monitoring sites were selected: Huzhong (HZ), Genhe (GH), Mao'ershan (MES), Changbaishan (CBS), Daganshan (DGS), Huitong (HT), Qianyanzhou (QYZ), and Dinghushan (DHS). HZ, GH, MES, and CBS reside in the northern part of the transect, and the others belong to the southern part of the transect. HZ and GH are located in remote mountain areas that are far away from cities, with forestlands of 147, 000 ha^{-1} and 553, 000 ha^{-1}, respectively. MES and CBS are surrounded by farmlands with spring wheat. DGS lies in Fenyi Town, and is approximately 30 km away from the center of Yichun City. HT and QYZ are located at forest ecological experiment stations, in Guangping Town, and in Taihe Town, respectively; they are surrounded by dry farmlands with paddy fields. Paddy fields, dry farmlands and factories surround the DHS study site; Guangzhou city, a typical economic area, is located 64 km east of DHS. Details for all of the sites are listed in Table 1, and geographical distribution of the sites is mapped in Fig. 1.

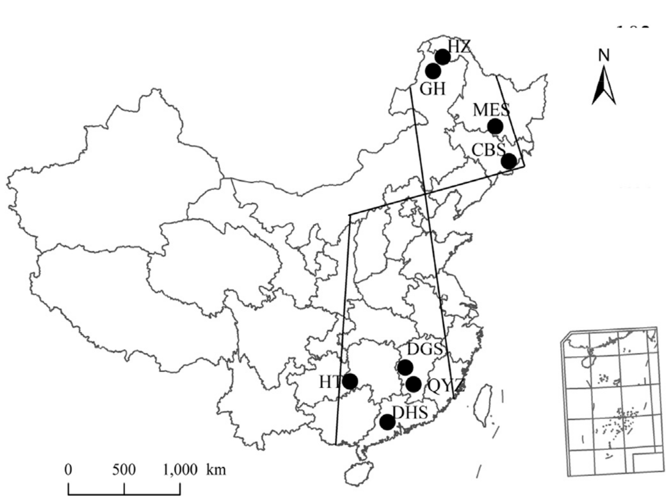

Fig. 1. Locations of eight monitoring sites (black dots). The region between the two lines represents the area of the North-South Transect of Eastern China (NSTEC).

2.2. Sampling and chemical analysis

In this study, IER columns were used to evaluate DIN deposition in throughfall (throughfall DIN deposition) and in precipitation (bulk DIN deposition) in forest ecosystems. Information about the design of the IER columns was illustrated in detail in a previous study (Sheng et al., 2013). The IER technique is superior to conventional methods (i.e., traditional rainfall collection), which are labor intensive and analytically expensive to implement on a broad scale (Fenn and Poth, 2004).

At each site, five IER columns were randomly placed under the canopy to measure throughfall DIN deposition, and five others were placed in an open area to collect bulk DIN deposition. Additionally, two IER columns with both ends sealed were installed to determine the background N in the ion resin (Fenn and Poth, 2004). Background N in the resin, although minimal, should be subtracted from the deposition data to determine the actual DIN deposition. All the IER columns were placed 1 m above the ground to avoid litter, debris, and other contaminants. From May 2008 to April 2011, the columns were retrieved monthly and new columns were installed, whereas observations at DGS were conducted monthly for two consecutive years (from May 2008 to April 2010) for a variety of reasons. Because of serious weather conditions, observations were conducted monthly only during the growing season (from May to October), whereas just one value for DIN deposition could be obtained during the nongrowing season (from November to April the following year) at HZ, GH, MES and CBS. Ion-exchange resin will lose its potency in cold winter weather; therefore, a conventional rainfall collection method was conducted at the four sites during the nongrowing season.

At the end of each field sampling, the resin columns were unscrewed from the funnel assembly, sealed at both ends, and returned to the laboratory. We then performed preliminary laboratory tests with the resin columns that were preloaded with a simulated deposition solution to test the absorption efficiency of the mixed resins and the recovery efficiency of the preloaded resins. The results showed that the absorption efficiency was more than 99.0% for $N-NO_3^-$ and $N-NH_4^+$, and the recovery efficiency was 90.3%–95.5% for $N-NO_3^-$ and 90.9%–100.0% for $N-NH_4^+$ after three KCl extractions. Therefore, the samples were mixed well and then filtered three times through 0.45 mm glass fiber filters with 100 mL 0.2 mol L^{-1} KCl solutions before analysis. $N-NO_3^-$ and $N-NH_4^+$ in the extract was analyzed by following a standard procedure on a continuous flow analyzer (TRAACS 2000, Bran-Luebbe Inc., Germany).

2.3. Calculation of DIN deposition

Monthly DIN deposition (*DIN*mon, kg-N ha^{-1}) collected by the IER columns was calculated according to the following formula (Sheng et al., 2013):

$$DIN_{\rm mon} = C_{\rm ex} \times V_{\rm ex}/100A \tag{1}$$

where *C*ex is N ($N-NO_3^-$ and $N-NH_4^+$) concentration (mg-N L^{-1})