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Research Highlight

Upward trend of nitrogen deposition curbed by the dual force of environmental regulation and social-economic structural change in China

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Nitrogen (N) is an important nutrient that is essential for all life on Earth. Although N accounts for 78% of the total atmospheric volume, it cannot be used by plants or animals unless it is converted to reactive nitrogen (N_r) such as ammonia (NH_3) or related nitrogenous compounds. The supply of reactive N has been the bottleneck in food production for centuries. Since 1913, the Haber-Bosch process has greatly improved the ability of humans to produce N fertilizers from atmospheric N. The rapid growth of the world's population since 1960 is closely related to the increase in food production caused by the increased use of N fertilizers [1]. Population growth further leads to increases in N-fixing crop cultivation, animal husbandry expansion, and fossil fuel consumption.

These human activities result in large amounts of oxidized (NO, HNO_3, and NO_2, referred to as NO_x) and reduced N (NH_x) being emitted into the atmosphere every year. The sources of NO_x and NH_x are closely related to the economic activities of humans. NO_x emissions have a wide distribution of sources, with substantial contributions from coal and oil consumption. Meanwhile, agriculture is the main source of NH_x, predominantly from fertilizer application and animal waste. These N compounds in the atmosphere are circulated to land and water in precipitation as wet and dry depositions. Nitrogen deposition affects climate, human health, and ecosystem processes in an interrelated way and has complex impacts on the sustainable development of human society [2,3]. Therefore, a better understanding of the spatial-temporal pattern of N deposition is critical for environmental management and policy development.

The pattern and environmental consequences of N deposition have been intensively studied over the past two decades [3]. As the fastest growing economy in the world, China's nitrogen deposition has received extensive attention. Simulations based on the intensity of China's industrial and agricultural activity suggest that China is one of the areas most affected by N deposition, and N deposition here will continue to grow rapidly over the coming years [3,4]. However, it is difficult to verify and validate the modeling results because of the lack of long-term monitoring of N deposition at the national scale. To better inform N management and environmental policy development, there is an urgent need to improve our understanding of the spatial and temporal variability in the total amount and relative contribution of each component of N deposition in China.

The recent work of Yu et al. [5], published in *Nature Geoscience*, provides a comprehensive picture of the changes in N deposition in China over the past 35 years. Over the past decades, a large number of studies have measured wet N deposition using ion exchange resin or directly from rain and snow samples. Yu et al. [5] constructed a comprehensive dataset of wet N deposition by pooling observational data from the following sources: Chinese Ecosystem Research Network (CERN), the Nationwide Nitrogen Deposition Monitoring Network (NNDMN), the National Acid Deposition Monitoring Network, and published literature. Dry N deposition is different to wet N deposition and involves complex interactions between airborne N compounds and land surface structure and is more difficult to estimate than wet N deposition. Therefore, although the levels of dry N deposition can be equivalent to, or even higher than, the levels of wet N deposition, many previous studies have had to ignore or simplify its contribution to total N deposition [6]. To address this challenge, Yu et al. [5] developed a remote sensing model to estimate the flux of dry N deposition using NO_2 satellite and ground measurements. Their model has provided a robust estimate of the spatial and temporal dry N deposition trend in China. Together, they built a unique national dataset that includes the spatial and temporal patterns of China's total N deposition and its dry and wet deposition components from 1980 to 2015.

Yu et al. [5] has revealed three important characteristics of the N deposition in China over the past few decades (Fig. 1): first, although the NO_3^- deposition in China has continued to increase in recent years, the NH_4^+ wet deposition has decreased significantly. Therefore, the total quantity of N deposition in China has changed from a state of rapid growth to being currently stable; second, between 2011 and 2015, the rate of dry N deposition continued to increase and reached the same level as wet N deposition; third, the contribution of NO_3^- deposition continues to increase, whereas the contribution of NH_4^+ deposition decreases, resulting in a decrease in the ratio of NH_4^+/NO_3^- in deposited N.

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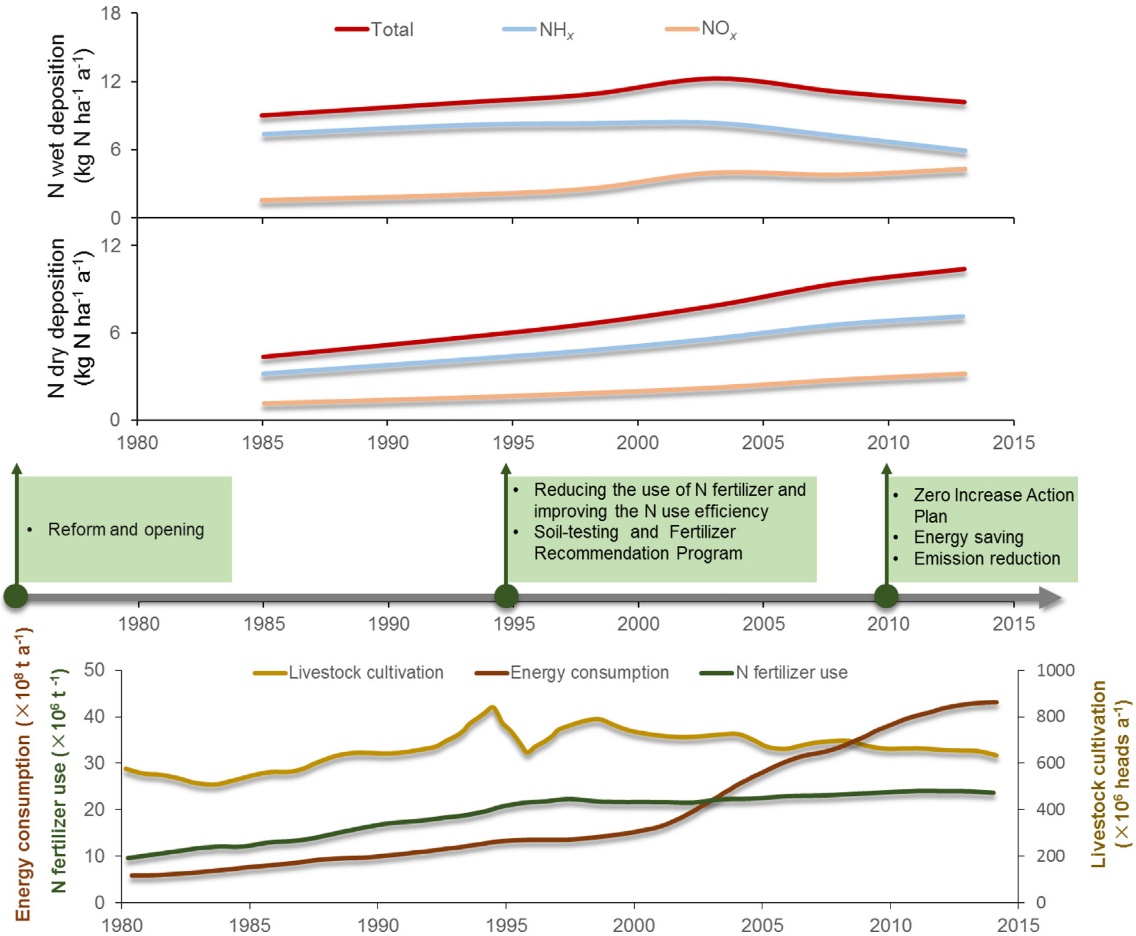

Fig. 1. Changes in socioeconomic structure and environmental policy deployments have altered China's N deposition pattern over the past 35 years. The trends in dry and wet N deposition and emission sources were drawn with reference to Yu et al. [5].

By integrating energy consumption, fertilizer use, and livestock production data, Yu and colleagues further demonstrated that the N deposition changes in China over the past 35 years are the combined results of rapid economic growth, transformation of industry infrastructure, and environmental policy deployment. The initial rapid increases in both dry and wet N deposition before 2000 were associated with a rapid increase in N fertilizer, livestock production, and energy consumption. In the mid-1990s, two policies related to fertilizer management, entitled "Reducing the use of N fertilizer and improving the N use efficiency" and "Soil-testing and Fertilizer Recommendation Program", gradually stabilized the growing trend of N fertilizer use. The "Zero Increase Action Plan" for national fertilizer use, implemented in the 2010s, led to a more rapid decrease in NH_x emissions from agricultural sources. The reduction in NH_x sources eventually resulted in a rapid decline in NH_x deposition and led to the stabilization of total N deposition after the 2000s. The observed increase in NO_x deposition was linked to the increase in energy consumption. In particular, rapid urbanization and an increase in vehicle numbers after 2000s caused a strong increase in NO_x emissions. Those socioeconomic structure changes eventually led to a reduced ratio of NH_4^+/NO_3^- in deposited N.

The study by Yu et al. [5] has important implications for a better understanding how air pollution affects the ecosystem and human health in China. Plants can not only take up the deposited N through their roots but can also take up N directly through the leaves in the canopy. Depending on the canopy structure, leaf traits, and functional groups, different plants have different preferences for dry or wet N deposition as well as ammonium or nitrate deposition. The changes in the N deposition pattern revealed by Yu et al. [5] can profoundly alter plant growth, biodiversity, and soil acidification in China. For example, the enhanced ecosystem productivity due to N deposition may be diminished, but the loss of biodiversity caused by N deposition can be alleviated [7–9]. With regards to human health, the exposure of particulate NH_4^+ and/or NO_3^- has been shown to trigger asthma attacks and respiratory infections and could cause heart attacks (EPA 2016). However, more studies are needed to explore how the shift in NO_x and NH_x sources and the changes in dry and wet N deposition could affect human health in different regions. In addition, temperature, precipitation, and relative air humidity are expected to change in future climate scenarios; these changes will further alter the physico-chemical behavior of airborne N, thereby changing the patterns of dry and wet N deposition. Climate changes could also significantly exacerbate or mitigate the impacts of N deposition on the ecosystem and human health [10]. Yu et al.'s [5] findings remind us that more research is needed to better manage the environment under a changing social-economic structure and climate.

Conflict of interest

The author declares that she has no conflict of interest.

Acknowledgments

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