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Research on acidification in forest soil driven by atmospheric nitrogen deposition

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ABSTRACT

Soil acidification is defined as the process in which exchangeable cations are leaching and soil H^+ concentration is raising thereby increases soil acidity. Changes in soil pH value and acid neutralizing capacity are mainly indicators of soil acidification. Soil acidification is considered to be a serious ecological and environmental issue, which not only reduces soil quality, but also decreases biodiversity of forest ecosystem and induces forest decline. With nitrogen (N) deposition rapidly increasing, its contribution to soil acidification becomes a major concern in the world. However, the impact of increased N deposition on soil acidification is not well addressed highlighting the need for further attention to the issue. In this paper, the studies on forest soil acidification induced by N deposition were reviewed. The factors related to soil acidification driven by N deposition were classified and discussed, which included soil acidic buffering capacity, N components in atmospheric N deposition, climate, plant species in forests, and N status in ecosystem. Iron (Fe) buffering phase and the consequent Fe toxicity occurring to the acidified soil caused by high N deposition were concerned. The scarcity of phosphorus (P) element induced by soil acidification was particularly emphasized. The research methods used to study soil acidification driven by N deposition were also evaluated. In the end we stressed the importance of the study on soil acidification especially in tropical and subtropical regions driven by N deposition and its mechanisms. This paper can serve for maintaining sustainable forest and agricultural ecosystems.

1. Introduction

Soil acidification is defined as the process in which base cations are leaching and soil H^+ concentration is increasing thereby enhances soil acidity, which is mainly manifested by the decline of soil pH and acid buffering capacity. Soil acid buffering capacity is specified as the molar mass of strong acid needed to reduce soil pH to a reference value from an initial value [1,2]. The whole process of soil acidification is divided into three stages, including (1) the buffering stage of base cations ($pH \geq 5$), (2) the buffering stage of Al ($5 < pH < 4$), (2) the buffering stage of Fe ($3 < pH < 4$) [3]. Currently the acidified soils usually undergo the second stage that is Al buffering, few show the characters of the third stage (i.e. Fe buffering) [1–4].

Soil acidification enhances the loss of nutrient elements (e.g. Ca and Mg), accelerates the mobility of toxic elements (e.g. Al, Mn and heavy metals), changes the communities of soil microorganisms and their activities, affects plant growth and nutrient uptake, increases the risk of plant disease and pest [5]. Finally, it results in the degradation of soil structure, the leaching of nutrients, biodiversity reduction of forest ecosystem and forest decline [6], etc.

Soil acidification is attributed to two main reasons: (1) the process of natural acidification, containing weathering, plant nutrient uptake, metabolic activities of soil microorganisms, etc.; (2) the process of soil acidification induced by anthropogenic activities, e.g. fertilization and acid deposition. When acid deposition received high concerns, N deposition only as one of its components was often ignored [7–9]. Increasing atmospheric N deposition is regarded as one of important global changes and becomes a hot topic, which has a great impact on terrestrial and ocean ecosystems for the increasing N input and rapid N cycle. It also strongly influences soil chemical and physical properties, and causes soil acidification, one of the most obvious changes. Forest soil acidification driven by N deposition is thought to be the key reason for forest decline [10,11] and plant diversity loss [12].

The research on the effects of forest ecosystem from N deposition could date back to 1960s and 1970s [13,14], following the presence of N Deposition Network research in Europe, e.g. item of NITREX and EXMAN [15]. The relative reports about the impacts on forest soil acidification and buffering capacity from N deposition have increased greatly, but mainly focused on the temperate regions with

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N-limit, especially Europe [16,17] and North America [18], few data from Asia [19–21]. China is one of the three regions with high level of N deposition in the world. N deposition is usually higher than 15 kg N ha^{-1} $year^{-1}$ [22] in China, and even exceeding 30 kg N ha^{-1} $year^{-1}$ in some cities, e.g. Guangzhou and Guiyang [23,24]. The rapid growth of atmospheric N deposition has induced forest soil acidification in China [21,25–29].

Even though there are more and more reports about soil acidification induced by N deposition, many works still need to be paid more attention to in the future: (1) the data of forest soil acidification induced by atmospheric N deposition are very scarce, compared to that by simulated N deposition; (2) the threshold of N deposition inducing soil acidification is not studied, even its acidification rate is neglected; (3) whether soil acidification driven by N deposition is the direct reason for reducing plant diversity needs to be confirmed, etc. Therefore, this paper made a thorough review of research on the soil acidification caused by N deposition from both home and abroad and its relative mechanisms, discussed the role of P element playing in the process of soil acidification and demonstrated the urgency and importance to carry out the research in tropical and subtropical regions existing in P-limitation and maintaining an obviously increasing N deposition in the future. It is very important to strengthen the research of soil acidification induced by N deposition and evaluate the contribution of different N components in N deposition to acidification, which could not only provide available reference for managing acidic soil and theoretic basis for mechanisms for the changes of biodiversity and productivity in forest ecosystem, but also service for enacting scientific policies to protect forest resources and reduce nitrogen oxide emission.

2. The research status both home and abroad

2.1. The study on soil acidification caused by N deposition

The earliest researches on soil acidification induced by adding N treatment were carried out by Nohrstedt et al. [30] in 1967 and Tamm and Popovic [31] in 1971, respectively, while the first report was attributed to Bergkvist and Folkeson [16]. From Table 1, the researches have increased since 2000 and kept an obviously rising trend between 2006 and 2010. The numbers of papers suggested that the research of soil acidification affected by N deposition is paid attention to. In China, the early study of N deposition was traced to 2002 and carried out by the team led by Professor Mo Jiangming, who designed permanent plots of simulated N deposition in Dinghushan, Guangdong Province. Then the method was widely adopted by domestic researchers. Nowadays, there are 24 field samples and covers

Table 1
Researches on nitrogen deposition drives soil acidification.

Sites	Vegetable types	Methods	Experimental time	Whether did soil acidification happen?	References
Sweden, Mangskog	Norway spruce	Simulated N deposition (urea)	29 years (fertilizer usage every 5 years, a total of four times)	No	[30]
Sweden, Betsele	A boreal forest	Simulated N deposition	34 years	No	[32]
Italy, Tuscania	Poplar plantation	Simulated N deposition	3 years	No	[33]
Sweden	A beech forest	Simulated N deposition	5.5 years	Yes	[16]
Sweden	Scot pine	Simulated N deposition	23 years	Yes	[31]
USA, Maine	Hardwood and softwood forests	Simulated N deposition	9 years	Yes	[18]
UK	Peat in the Scottish Borders	Simulated N deposition	5 years	Yes	[34]
North Wales, Ruabon in Denbighshire	An upland moor	Simulated N deposition	10 years	Yes	[35]
Sweden, Lisselbo and Norrliden	Scots pine stands	Simulated N deposition	30 years	Yes	[36]
UK	Grassland	Simulated N deposition	8–10 years	Yes	[37]
Slovakia, Tatra National Park	Alpine grassland	Simulated N deposition	3 years	Yes	[3]
Sweden, Gårdsjön	A coniferous-forest Norway spruce	Simulated N deposition	19 years	Yes	[38]
Switzerland	Norway spruce and an alpine stands	Atmospheric N deposition		Yes	[17]
USA, California	San Bernardino Mountains	Atmospheric N deposition		Yes	[39]
Austria	Beech and spruce stands	Atmospheric N deposition		Yes	[40,41]
UK	68 Grassland sites	Atmospheric N deposition		Yes	[42]
From the Atlantic through Central Europe to the Baltic terrestrial ecoregion	19 coastal dune sites	Atmospheric N deposition		Yes	[43]
Border between Ukraine and Slovakia	Primeval deciduous and coniferous forests	Atmospheric N deposition		Yes	[44]
Tieshanping, Chongqing and Caijiatang, Hunan Province	Masson pine forest	Atmospheric N deposition		Yes	[25]
Chongqing, Hunan Province, Guizhou Province, Guangzhou city, Guangdong Province	Pine forest, conifer and broad-leaved mixed forest and evengreen broadleaved forest	Atmospheric N deposition		Yes	[26]
Yingtan, Jiangxi Province	Coniferous forest broad-leaved forest	Simulated N deposition (leaching experiment with soil column)	8 months	Yes	[10,11]
Tieshanping, Chongqing	Masson pine forest	Simulated N deposition	1 year	Yes	[45]
Guangzhuang-owned Forest Farm in Shaxian, Fujiang Province	Chinese fir plantation	Simulated N deposition (urea)	3 years	Yes	[27]
Guangzhuang-owned Forest Farm in Shaxian, Fujiang Province	Chinese fir plantation	Simulated N deposition (urea)	3 years	Yes	[46]
Dinghushan, Guangdong Province	Evengreen broad-leaved forest, conifer and broad-leaved mixed forest and coniferous forest	Simulated N deposition	14 month, and 26 months	Yes	[21]
Xilin Hot, Inner Mongolia	*Leymus Chinensis* Grassland	Simulated N deposition	3 years	Yes	[28]
Mao'er Mountain, Heilongjiang Province	Chinese Larch forest	Simulated N deposition	6 years	Yes	[29]