Effects of the nitrogen deposition on the forest ecosystems: An overview

by

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A CAUTION TO THE READER

This HBScF thesis has been through a semi-formal process of review and comment by at least two faculty members. It is made available for loan by the Faculty of Natural Resources Management for the purpose of advancing the practice of professional and scientific forestry.

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ABSTRACT

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Keywords: nitrogen Deposition; forest ecosystem; nitrogen saturation; nitrogen limitation; biodiversity.

Human activities exacerbate the production and emission of reactive nitrogen and lead to the increase and globalization of nitrogen deposition. At present, the interference of human activities in the global nitrogen cycle has exceeded the boundaries of the safe operation of the Earth system. High nitrogen deposition has threatened the health and safety of the ecosystem and has become a hot issue that needs to be clarified and solved in the process of ecological civilization construction. This review summarizes the impact of nitrogen deposition on forest ecosystems from the aspects of nitrogen deposition on forest plants, animals, and microorganisms by referring to the literature on nitrogen deposition, introduces the corresponding response mechanism, and includes how we analyze and compare the data (methodology) and clarify what the effects of Nitrogen deposition on the forest ecosystems, how forest ecosystems respond and acclimate long-term N deposition(results).

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INTRODUCTION & OBJECTIVE

Atmospheric nitrogen deposition has become a major factor in global change. In recent years, due to the burning of fossil fuels and the use of nitrogen fertilizers, the deposition of nitrogen (N) in the global atmosphere has increased significantly and severely affects the material cycle of terrestrial ecosystems. In the context of the globalization of nitrogen deposition, this review mainly emphasizes the effects on the forest ecosystem. The effects of nitrogen deposition on forest ecosystems are reviewed in terms of the effects of nitrogen deposition on forest plants, animals and microorganisms, and the corresponding response mechanisms are described.

Literature Review

Atmospheric nitrogen deposition has become a major factor of global change. (STEVENS C. J ,2016)In recent years, the global atmospheric nitrogen (N) deposition has increased significantly due to the burning of fossil fuels and the use of nitrogen fertilizers. It has seriously affected the nutrient cycle of terrestrial ecosystems. (BERGSTRM A K and JANSSON ,2006)The current center of distribution of global nitrogen deposition is changing: from developed countries such as Europe and the United States to developing countries and from temperate regions to tropical and subtropical regions. (GALLOWAY J N et al. 2004)

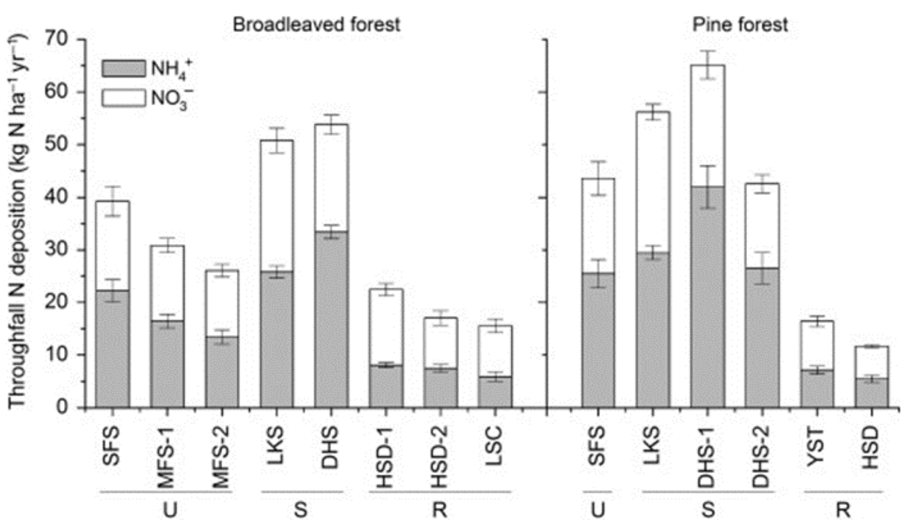

Figure 1: Nitrogen deposition in throughfall in 14 forests along the study transect. U, S and R denote urban, suburban, and rural sites, respectively.

Nitrogen is a limiting factor for the net primary productivity of terrestrial plants, and the increase of atmospheric nitrogen deposition contributes to the net primary productivity of plants and the improvement of soil carbon sequestration capacity but also has adverse effects such as soil acidification, loss of biodiversity, and increased nitrogen loss. Researchers have become increasingly interested in the study of nitrogen deposition.(LEBAUER D S, TRESEDER K K. 2008)

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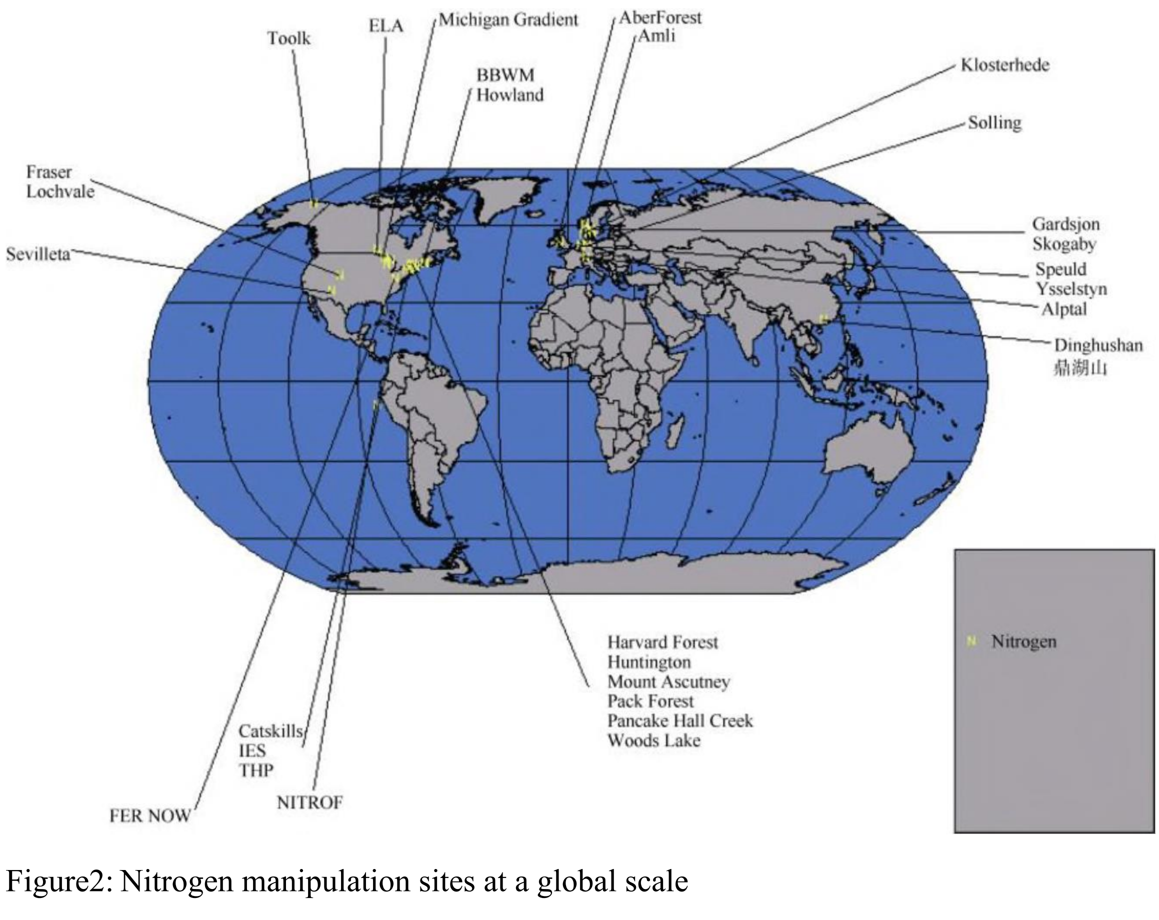

Figure2: Nitrogen manipulation sites at a global scale

The problem of nitrogen deposition is widespread worldwide due to the intensification of human activities and the massive use of nitrogen fertilizers, and nitrogen, as an important element of life, is ubiquitous in people's lives. As an important oxygen bar and key support for human survival and development, forests are vital to human health. Excessive nitrogen deposition can lead to a series of ecological problems, especially affecting forests. By reviewing the domestic and international literature on nitrogen deposition, I review the effects of nitrogen deposition on forest ecosystems in terms of its effects on forest plants, animals and microorganisms and introduce the corresponding response mechanisms.

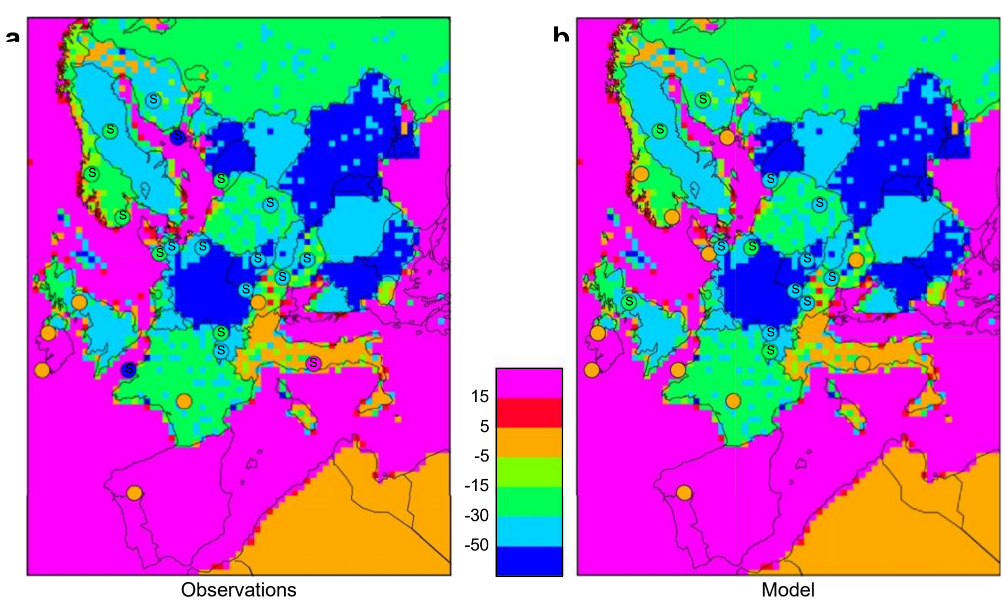

Figure3:Percent change of NO_x emissions 1980_e2003 (field), versus trends of oxidized nitrogen in precipitation (bullets). The sites which are marked with 'S' show statistically significant trends, and the colour shows the magnitude of the change in concentrations.

1.0Effects of nitrogen deposition on forest plants

Forest ecosystems, as the mainstay of terrestrial ecosystems, play an extremely important role in the global carbon cycle(FALKOWSKI P et al.2000). Many experts believe that forests have a higher rate of nitrogen deposition and that nitrogen deposition has a greater impact on forest ecosystems than on other terrestrial ecosystems (GILLIAM F S， ROBERTS M R. 2003). The structure and function of forest ecosystems are generally complex, and changes in their diversity are more related to changes in understory plant diversity. The effects of nitrogen deposition on understory biodiversity in forest ecosystems have also been frequently reported (STRENGBOM J et al. 2001). The effects of N deposition on biodiversity and different life types of plants are debated, with some studies suggesting that N deposition reduces understory plant species diversity; while a 3-year N addition experiment in a temperate coniferous forest by Du (DU E Z.2017)found that N addition did not change understory plant species diversity; a 1-year fertilization experiment in a temperate mixed coniferous forest by Junyu Hu et al. (Junyu Hu et al. 2014)showed that low N treatment increased understory species diversity, while high N treatment inhibited it. Numerous studies have shown that the response of different plant life types to N deposition in forest ecosystems is largely the same as that of different plant life types in grassland meadows and other ecosystems, i.e., N deposition promotes the growth of grasses and deciduous shrubs and suppresses the growth of miscellaneous grasses and evergreen shrubs(VAN DOBBEN H F. et al. 1999). It has also been shown that nitrogen deposition has no significant effect on the growth of both herbaceous and shrub plants (LU X K et al. 2010). Of course, the effect of nitrogen deposition on biodiversity also varies depending on the duration of fertilization(GILLIAM F S et al. 2016). One study found that three years of nitrogen deposition increased the abundance of the understory plant Quercus manzanita, while four years of nitrogen deposition decreased the abundance of Quercus manzanita(STRENGBOM J. et al. 2003).

1.1 Effect of nitrogen deposition on chemical elements of forest plants

Atmospheric nitrogen deposition can affect plant elemental balance directly or indirectly by altering the composition of soil chemical elements(GILLIAM F S et al.2018.)and eventually lead to elemental imbalance at the ecosystem level (LU X K. et al. 2010). For now, there are studies on the effects of nitrogen deposition on the chemical elements of forest plants, mostly above ground, while there are relatively few studies underground. Above ground, Elser, J. J. et al. (2007) observed that nitrogen deposition can lead to increased availability of nitrogen in the ecosystem, promoting plant growth and altering the nutrient balance. This can lead to higher nitrogen to phosphorus (N:P) ratio in plant tissues, which may decrease phosphorus availability and affect overall plant growth and productivity.

Dise, N. B., & Wright, R. F. (1995) found that nitrogen deposition can also alter the competitive dynamics among plant species, which may influence the species composition and biodiversity of forest ecosystems. Nitrogen deposition may favour nitrophilous plants, those that thrive in nitrogen-rich environments, over other species that are less adapted to high nitrogen conditions.

Nordin (2005) reported that nitrogen deposition could influence the production of secondary metabolites in plants, such as phenolic compounds and alkaloids, which can affect herbivore-plant interactions and overall ecosystem functioning.

Underground part Treseder, K. K. (2008) highlighted that nitrogen deposition could impact the belowground ecosystem by altering the composition and activity of soil microbial communities. This may affect the decomposition of organic matter, nutrient cycling, and plant-microbial symbioses, which can have consequences for plant nutrient acquisition and overall ecosystem functioning.

Liu .et al. (2011) found that increased nitrogen deposition can lead to the acidification of soil, which can have negative effects on the availability of essential nutrients such as calcium, magnesium, and potassium. This can, in turn, affect plant nutrient balance and potentially limit plant growth.

Zhu J. et al. (2015) discovered that nitrogen deposition can influence the distribution of fine roots in the soil, which play a critical role in nutrient and water uptake. Changes in fine root distribution can have consequences for plant nutrient acquisition and overall ecosystem functioning.

While there has been considerable research on the effects of nitrogen deposition on aboveground components of forest ecosystems, belowground research remains relatively limited. As understanding of the complex interactions between nitrogen deposition and ecosystem functioning continues to grow, it is important to expand research efforts to understand better the consequences of these changes on both aboveground and belowground components.

There are 2 main reasons for the different responses of plant elemental chemistry to nitrogen deposition in different ecosystems: first, plants have developed different developmental characteristics in the evolution of long-term survival, resulting in different sensitivities to nitrogen deposition. In addition, the adaptability of plants to self-adjust is a major influencing factor. Second, the external environment in which plants develop can also influence plant response. For example, the temperate regions of northern China are generally considered to be nitrogen-limited. Still, the southern tropical subtropics are nitrogen-rich and mostly phosphorus or other cation-limited, so forest plant responses to nitrogen deposition may differ.

1.2 Effect of nitrogen deposition on the growth of forest plants

Global nitrogen addition typically exhibits stimulatory effects on the growth of different plant species (XIA J Y,WAN S Q. 2008). The sensitivity to N deposition response varies among ecosystems and functional taxa, with secondary forest tree growth generally more sensitive than primary forest and herbaceous plants more sensitive than woody plants (SIDDIQUE I. et al. 2010). Also, the effect of nitrogen deposition on net primary productivity or plant growth in forests varies with the amount of nitrogen deposition, with a non-linear relationship that is common in ecology (DE VRIES W. et al. 2014).

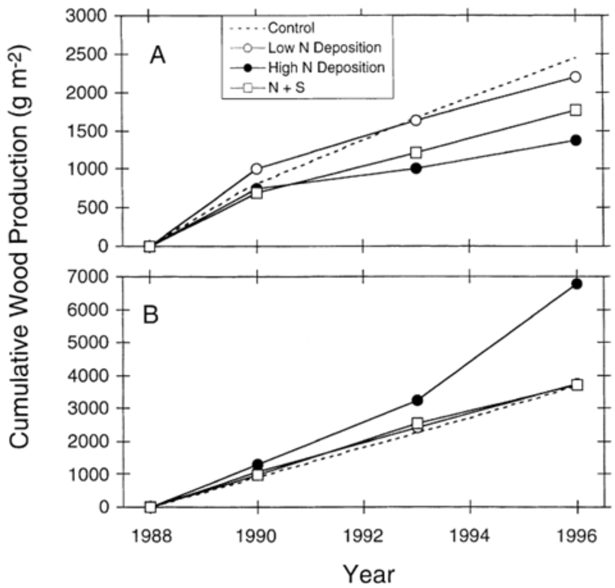

Figure 4.:Cumulative wood production from 1988 to 1996 in g m^{-2} for the pine stand (A) and hardwood stand

The earlier view was that atmospheric nitrogen deposition is a nutrient for forests, but it also needs to be in the right amount, and if excessive nitrogen deposition causes a certain degree of cumulative effect. For example, in a long-term ecosystem study of the Harvard Forest in the United States, which is in the middle of the temperate zone, each stand biomass increased to varying degrees compared to the control for 9 years of nitrogen application treatments, but after 9 years, forest stand biomass decreased with increasing nitrogen input, and stand biomass in the high nitrogen treatment sample was significantly reduced compared to the control (MAGILL A H. et al.2000).

From another perspective, the most serious hazard of excessive nitrogen deposition to forests is the formation of acid rain along with SO2 from industrial waste gases thus directly harming the forest, thinning the forest canopy, reducing resistance to pests and diseases, and gradually worsening with time and possibly even leading to forest decline (Wang Honglin .2004). In addition, long-term acid rain in forests can lead to soil acidification, which is mainly manifested by the decrease in soil pH, decrease in salt base saturation, massive loss of Ca2+, and activation and migration of Al3+.

1.3Effect of nitrogen deposition on forest vegetation diversity

Elevated atmospheric nitrogen deposition has become the third largest driver of global diversity loss(SALA O E 2000.).Existing studies have focused on understory plant diversity because tree plants respond more slowly to environmental factors compared to understory plants. Long-term nitrogen deposition changes the species composition of the understory, but the degree of change depends on the forest type, functional taxa, and influencing factors such as nitrogen status.

In tropical/subtropical primary forests, Lu et al. (LU X K. et al. 2010.)found that 5 years of high N addition [>100 kg/(hm2-a)] significantly reduced understory plant diversity and suggested for the first time that the negative effects were mainly related to soil acidification mechanisms rather than traditionally competitive ones. Wu et al. (W J P. et al. 2013.)showed that 8 years of high N addition [>120 kg/(hm2-a)] may reduce understory plant richness by reducing Hu et al. (HUANG Y M . et al. 2015.)suggested that the reduction in the abundance of major species in the understory may be the result of a combination of nitrogen saturation and soil acidification by comparing the effects of NH4NO3 and NaNO3 treatments in a subtropical Sargassum pine forest. In addition, N deposition effects are also related to land use practices, with plant diversity in planted or secondary forests being relatively insensitive to the response of N deposition compared to primary forests(Guoliang Xu. et al. 2005.).

2.0Effects of nitrogen deposition on forest fauna

2.1 Effect of nitrogen deposition on the biomass of forest soil fauna

Soil fauna occupies an important role in both soil and the ecosystem, and nitrogen addition can have an effect on soil fauna. The results of the research in the artificial nursery sample in the South Asian tropics showed, firstly, that nitrogen deposition as a whole has always shown a facilitative effect on the soil fauna during the 1-year test treatment; secondly, there is a clear threshold effect of nitrogen deposition increase, with the medium nitrogen treatment (100 kg/hm2) always being the peak and the threshold of change in the values of each parameter of the fauna during the one-year period(Guoliang Xu et al.2005.). Studies have shown that the threshold effect of N deposition does exist and that N input within certain limits is beneficial, but excessive N deposition can have negative effects(MAGILL A H . et al. 2000.)and is also informative for plants and microorganisms. A study by Xu et al. (XU G L. et al. 2005)on three typical forests (monsoon evergreen, mixed coniferous and coniferous forests) in South Asia showed that one year of N treatment did not significantly affect soil animal biomass. However, low N treatments [50 kg/(hm2-a)] showed varying degrees of increase in biomass in each stand, while high N treatments [100 kg/(hm2-a)] all showed decreases.

In addition, the effects of nitrogen deposition on different soil fauna may differ. Studies in temperate plantation forests showed that fertilization altered the density of different predatory soil fauna in both stands, resulting in a decrease in the number of saprophytic soil fauna and an increase in the number of phytophagous soil fauna but no significant change in the number of predatory soil fauna; this suggests that the response of different predatory soil fauna to N deposition is also inconsistent [88]. It has also been shown that nitrogen addition has no significant effect on phytophagous nematode density but can alter the interaction between alien organisms (e.g., earthworms) and phytophagous nematodes, thus potentially affecting ecosystem function(SHAO Y H. et al. 2017.)

There need to be more reported studies on the effects of nitrogen deposition on soil fauna in forest ecosystems, but the amount of nitrogen deposition has been suggested in studies on the effects of nitrogen addition to agricultural soils on soil fauna. The positive effect of nitrogen treatment within coniferous forests was not only manifested in the treatment sample sites but also significantly increased the biomass of soil fauna taxa in the control sample sites (Guoliang Xu et al.2005.).

2.2 Effects of nitrogen deposition on forest faunal diversity

Faunal communities can respond sensitively to weak environmental changes (XU G L et al. 2006). Many external factors may influence the results of the study to some extent. There are few studies on the effects of nitrogen deposition on fauna, such as the NITREX project, and related studies conducted by Huhta et al. (HUHTA V. et al. 1988)and Xu et al., which mostly concluded that increased nitrogen deposition decreased soil faunal diversity. However, it has also been shown that a low concentration of N deposition increases faunal diversity to some extent(BOXMAN A W. et al. 1998). For example, Guoliang Xu et al. found that a 16-month N treatment promoted faunal community diversity in a study of soil fauna in a Horsetail pine forest, so the threshold effect is of interest. In addition, the study by Xu et al. on mixed conifer forests concluded that nitrogen deposition had no significant impact on soil fauna, which may be related to the amount of nitrogen deposition. Therefore, it is likely that the decrease in forest faunal diversity is caused by the hazards of soil acidification and soil structural damage produced by excessive N deposition.

3.0Effect of nitrogen deposition on forest microorganisms

Soil microorganisms are adapted to the consistently low nitrogen environment and excessive nitrogen deposition can have an impact on soil microorganisms. Excessive nitrogen deposition can not only change the structural composition of microbial communities, as evidenced by a decrease in the ratio of fungal to bacterial biomass, changes in the associated abundance of soil fungi bacteria, a decrease in fungal biomass, a decrease in the number of soil microorganisms, changes in the structure of microbial communities, and even changes in the biological functions of some microorganisms, such as a decrease in soil respiration rate and a decrease in soil enzyme activity. In an experiment to study the effect of nitrogen deposition in Harvard Forest on its soil microorganisms, Wallenstein (WALLENSTEIN M D. 2004)found that the fungal to bacterial ratio decreased with increasing levels of nitrogen application. Therefore, nitrogen application inhibited the growth of fungi, which were significantly dominant in ecological environments where the limiting factor was carbon and less dominant in environments where nitrogen was present, indicating that fungi were not highly utilizing nitrogen.

The effect of nitrogen addition on microbial load was also related to the amount, type, season, microbial species and forest type of nitrogen addition.

3.1 Effect of nitrogen deposition on soil microorganisms

Nitrogen addition can change soil microbial composition.

First, N addition can change the composition of the fungal community (fungi, tussock mycorrhizal fungi and ectomycorrhizal fungi).

Second, N addition affects the bacterial composition, and based on phospholipid fatty acid analysis techniques, N addition decreases the relative abundance of Gram-negative bacteria and increases the Gram-positive bacteria/Gram-negative bacteria ratio(WANG C et al. 2018)

Third. Nitrogen addition affects the fungal to bacterial ratio.

3.2 Effect of nitrogen deposition on microbial diversity

The input of excessive nitrogen deposition and the appearance of nitrogen saturation will change the structure and function of microbial communities, while excessive nitrogen deposition will reduce the microbial population and decrease species diversity (LILLESKOV E A et al. 2001). Under nitrogen deposition conditions, communities dominated by both nitrogen-loving and nitrogen-averse species will gradually evolve into a new community structure with nitrogen-loving species as the dominant species and nitrogen-averse species gradually reduced to declining species (DEFOREST J L . et al. 2004).In addition, in ectomycorrhizal fungi, although short-term nitrogen deposition promotes population increase and substrate production, long-term nitrogen deposition has a suppressive effect and therefore reduces the expansion capacity of mycorrhizal root systems, fungal substrate production, and species richness(LILLESKOV E A . et al. 2002).The effect of N deposition on soil bacteria is usually less pronounced than that of fungi. It may be related to the N status of the ecosystem, vegetation composition, and the duration of N application, and N deposition within certain limits may be beneficial for biodiversity (ABER J . et al. 1998.).In addition, most studies have shown that an increase in N deposition reduces the number of ectomycorrhizal fungi, species richness and community composition.

4.0 MATERIAL & METHOD

By reviewing the literature on nitrogen deposition, I review the effects of nitrogen deposition on forest ecosystems in terms of its effects on forest plants, animals and microorganisms and introduce the corresponding response mechanisms.

By reading and understanding the literature which has been found on the website and getting the conclusion of the essay. In the literature, we obtained data on the effects of nitrogen deposition on forest soil, forest plants, forest phytochemical elements, forest animals and on microorganisms. Through data analysis and comparison, we conclude the changes and effects of nitrogen deposition on the structure and function of forest ecosystems.

5.0 Discussion

The impact of nitrogen deposition on forest ecosystems is reviewed from the aspects and perspectives of nitrogen deposition on forest plants, animals and microorganisms, the corresponding response mechanism is introduced, and future research work has prospected.

In the process of conducting the review and reading a large amount of relevant literature, I mainly found the following problems：

I. The selection of tree species used for nitrogen deposition studies is indeed limited. This is because studies usually focus on a few common or economically important species. Indeed considering the availability of resources, ease of research, and relevance to a particular ecosystem or region, focusing research on common and economically important species is currently the best practice for nitrogen deposition research. However, as research continues, it is important to recognize that expanding the range of species studied is critical to better understand the overall impact of nitrogen deposition on forest ecosystems.

Given the current research limitations and the need for a more comprehensive understanding of the impacts of nitrogen deposition on forest ecosystems, focusing on tropical tree species or understudied species from various ecosystems could be a valuable direction for future studies. One potential candidate for the next study could be the tropical tree species from the Amazon rainforest. For example the Brazil nut tree (Bertholletia excelsa). The rationale for choosing this species includes the following:

1. Understudied ecosystem: As mentioned earlier, tropical forests have received comparatively less attention in nitrogen deposition research than temperate and boreal forests. By focusing on a tropical tree species, researchers can begin to address this knowledge gap and better understand the impacts of nitrogen deposition on these vital ecosystems.
2. Ecological importance: The Brazil nut tree plays a crucial ecological role in the Amazon rainforest, providing habitat and resources for various species. Understanding the effects of nitrogen deposition on this tree species will provide insights into how these changes might impact the broader ecosystem.
3. Economic and social significance: Brazil nuts are an important non-timber forest product with significant economic value for local communities. Studying the effects of nitrogen deposition on the Brazil nut tree will help inform sustainable management practices that support both forest conservation and local livelihoods.
4. Climate change and deforestation: The Amazon rainforest is currently facing threats from climate change and deforestation. Understanding how nitrogen deposition interacts with these stressors can provide valuable information for the development of effective conservation strategies.

II. There is a lack of an international standard system for nitrogen deposition research methods, and differences in research methods appear in various aspects. Due to the differences in topography, climate, culture and their own development, research methods and instrumentation for nitrogen deposition measurement vary around the world, resulting in differences in research results, making it difficult to make uniform conclusions and scientific comparative analysis of the real ecological situation

For examples:

1. Sample collection:

   The National Atmospheric Deposition Program (NADP) uses a standardized network of wet deposition collectors in the United States. These collectors are typically open only during precipitation events to avoid capturing dry deposition.

   In Europe, the European Monitoring and Evaluation Programme (EMEP) uses a combination of bulk deposition and wet-only collectors. Bulk deposition collectors remain open continuously, capturing both wet and dry deposition.

   In China, a mix of bulk deposition and wet-only collectors is used, with some studies employing methods similar to those of the NADP, while others follow EMEP guidelines.

2. Frequency of sampling:

   In the United States, the NADP typically collects samples on a weekly basis.

   European countries participating in the EMEP program generally collect samples every week or every two weeks, depending on the specific research objectives and available resources. In countries like India or Brazil, where monitoring networks may be less developed, the sampling frequency can vary widely, from weekly to monthly or even less frequent intervals.

3. Preservation methods:

Researchers in the United States and Europe often filter and refrigerate samples or freeze them until analysis to preserve nitrogen species in collected samples. In some developing countries, where resources and infrastructure might be limited, researchers may need to rely on less optimal preservation methods, such as acidification or immediate analysis, without proper storage.

4. Measurement techniques:

In developed countries like the United States and countries in Europe, advanced analytical methods like ion chromatography or inductively coupled plasma mass spectrometry (ICP-MS) are commonly used for measuring nitrogen concentrations in deposition samples. In developing countries, researchers might be more likely to use colorimetric methods or less sophisticated equipment due to limited resources and access to advanced analytical instruments.

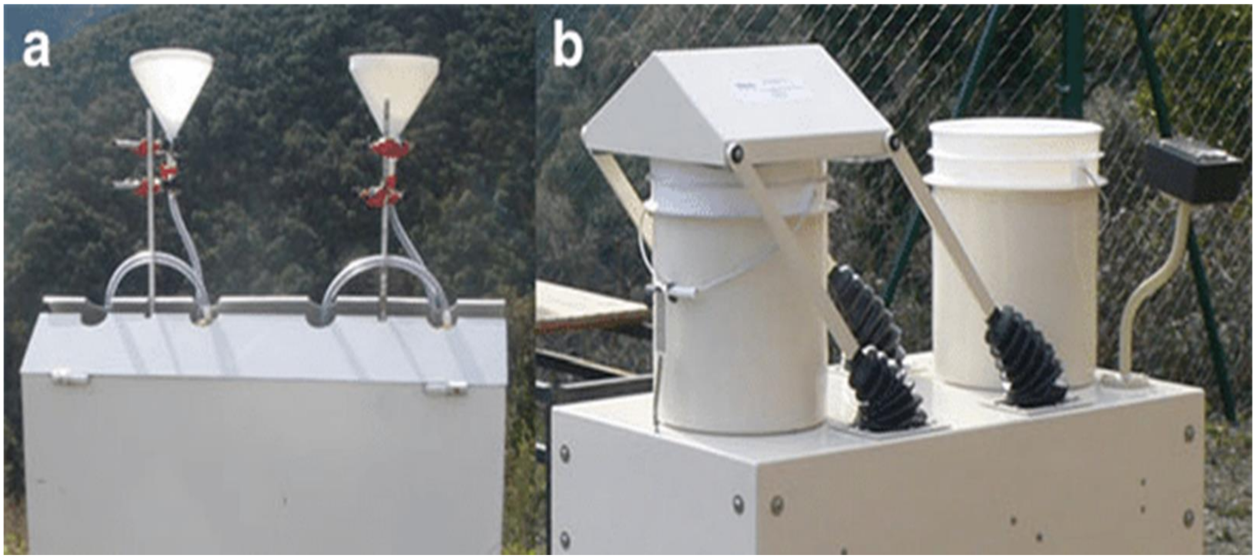

Figure 5: a open bulk deposition collectors;b wet/dry sampler

And these methodological differences could lead to changes in conclusions.A study by Vet et al. (2014) compared nitrogen deposition measurements across different monitoring networks in North America and Europe, revealing discrepancies in deposition estimates due to methodological differences. The study found that the use of bulk deposition collectors, such as those used in the European Monitoring and Evaluation Programme (EMEP), often resulted in higher nitrogen deposition estimates than wet-only collectors, which are used in the United States' National Atmospheric Deposition Program (NADP). It's not the only case; a meta-analysis conducted by Bobbink et al. (2010) assessed the effects of nitrogen deposition on terrestrial plant species diversity across different ecosystems, including forests. The study found that the impacts of nitrogen deposition on plant species diversity varied depending on the ecosystem type and the specific response variables measured (e.g., species richness, evenness, or diversity indices). The authors noted that methodological differences between studies, such as experimental design, nitrogen application rates, and response variable selection, could contribute to the observed variability in the results. Earlier experiments illustrate a similar situation, Lovett et al. (2000): This study compared wet-only and bulk deposition measurements of nitrogen and sulfur at two sites in the northeastern United States. The authors found that bulk deposition measurements provided higher estimates for both nitrogen and sulfur deposition than wet-only measurements.(At the first site, the bulk deposition collector measured 7.1 kg N ha^-1 yr^-1, while the wet-only collector measured 5.0 kg N ha^-1 yr^-1. At the second site, the bulk deposition collector measured 9.2 kg N ha^-1 yr^-1, and the wet-only collector measured 6.4 kg N ha^-1 yr^-1.)

So how to improve this situation and reduce the avoidance of this situation, in particular, will be the direction of our future research.

III. In my collection of literature, I also found a point that may need attention in the future Currently, Most of the nitrogen deposition experiments have been conducted over short periods of time (<10 years), like the experiments about the Nitrogen addition in South Asian tropical forests, Xu et al. (2005) they did a one year study, they investigated the effects of nitrogen deposition on soil fauna in three typical forests in South Asia. The researchers found that low nitrogen treatments increased biomass in each stand, while high nitrogen treatments decreased biomass, suggesting a threshold effect of nitrogen deposition on soil fauna. But in long term, continuous nitrogen deposition might lead to soil acidification and structural damage, potentially harming soil fauna and their habitats. Over time, the positive effects of low nitrogen treatments might diminish, while the negative effects of high nitrogen treatments could become more pronounced, ultimately leading to a decline in soil faunal biomass and diversity. Whether the results will still be the same as time passes, we cannot be sure. Another example, In a study by Shao et al. (2017), researchers examined the effects of nitrogen addition on soil fauna in temperate plantation forests. They found that fertilization altered the density of different predatory soil fauna, resulting in a decrease in the number of saprophytic soil fauna and an increase in the number of phytophagous soil fauna. However, there was no significant change in the number of predatory soil fauna.But as nitrogen deposition continues, the balance between different groups of soil fauna might shift, potentially affecting ecosystem processes, such as nutrient cycling and decomposition. Over time, the altered densities of saprophytic, phytophagous, and predatory soil fauna might have cascading effects on other components of the ecosystem.

6.0 Conclusion

The purpose of this study is twofold. The first is to review the results of the studies that have been obtained on the effects of nitrogen deposition on forest ecosystems. Nowadays atmospheric nitrogen deposition is becoming increasingly significant as a global change factor, especially for forest ecosystems. Nitrogen deposition has significant and complex effects on forest ecosystems, impacting soil fauna, faunal diversity, and microorganisms. While nitrogen deposition is a natural process, human activities have increased the amount of nitrogen entering ecosystems, which can lead to a range of consequences. Low levels of nitrogen deposition can have positive effects on soil fauna and faunal diversity, but excessive nitrogen deposition can result in negative consequences, such as decreased soil faunal diversity and changes in the structure and function of microbial communities. The threshold effect of nitrogen deposition is an important aspect to consider, as it helps to understand the balance between beneficial and detrimental effects on forest ecosystemsThe response of soil fauna and microorganisms to nitrogen deposition can vary depending on factors such as forest type, nitrogen concentration, and the specific species involved. Understanding these complex interactions and consequences is crucial for developing effective management strategies to mitigate the negative effects of human-induced nitrogen deposition and maintain the health and stability of forest ecosystems.

The second is to discuss the problems of differences in research methods and incomplete selection of study subjects. The impact of nitrogen deposition on forest ecosystems is a complex issue that requires a multifaceted approach to fully understand its effects on plants, animals, and microorganisms. The current state of research reveals several limitations and challenges, such as the limited selection of tree species studied; another challenge is the lack of international standardization in research methods, which can make it difficult to compare findings across studies. Furthermore, Currently, Most of the nitrogen deposition experiments have been conducted over short periods of time (<10 years).

In order for subsequent studies to reach more general adaptation conclusions, we can do the following initiatives. First, researchers should consider investigating a wider variety of tree species, particularly those from tropical ecosystems or underrepresented regions. This will help provide a more comprehensive understanding of the impacts of nitrogen deposition on different forest ecosystems and tree species. The development of standardized protocols for sample collection, preservation, and measurement, as well as inter-laboratory comparisons and proficiency testing, can harmonize methods and promote best practices. Encouraging detailed reporting of research methods in publications and promoting international research collaboration can facilitate the exchange of expertise and contribute to methodological improvements, while enhanced support for international and regional monitoring networks can further harmonize research methods and data sharing. Combining remote sensing and modelling approaches with field measurements can provide a more consistent and comprehensive assessment of nitrogen deposition and its impacts on forest ecosystems. By implementing these strategies, the scientific community can gain a more accurate understanding of the impacts of nitrogen deposition on forests, ultimately providing the basis for more effective management and conservation measures worldwide. And to better understand the long-term effects of nitrogen deposition on forest ecosystems, researchers should design and implement experiments that extend beyond the typical short-term duration of current studies. Long-term monitoring of ecosystem responses to nitrogen deposition will help provide insights into how these ecosystems may change over time. There is also a need to enhance the coupling with other global change factors (e.g.global warming, increasing CO2 concentration, changing rainfall patterns, etc.) need to be coupled to better assess the future development trend of ecosystems. And researchers, policymakers, and forest managers should work together to incorporate the results of nitrogen deposition research into the development of policies and management practices aimed at protecting forest ecosystems and ensuring their long-term sustainability.

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APPENDICES

Some figures could indicate the results of the thesis.