Human Alteration of the Nitrogen Cycle and Its Impact on the Environment

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Abstract. Nitrogen(N) is a key element that controls the functions and dynamics of Earth’s various ecosystems. In recent years, however, human activities, including the use of N fertilizers and the combustion of biomass and fossil fuels, have been injecting artificially transferred nitrogen into the atmosphere. Human alteration of the nitrogen cycle poses a threat to various aspects of the environment. Organisms in terrestrial and aquatic ecosystems used to lower nitrogen levels struggle with the new conditions; plant species richness and biodiversity are reduced due to excessive use of N fertilizers; reactive nitrogen in different forms negatively alter the ozone layer and exacerbate the greenhouse effect. Although most nitrogen inputs are serving human needs, the long-term environmental consequences are serious and should not be ignored.

1. Nitrogen Facts

All life depends on nitrogen, one of the most important elements on planet Earth, to survive. Nitrogen is the major component of DNA, RNA, and organic molecules like proteins.[1] Although the Earth’s surface contains 78 percent nitrogen gas, most organisms cannot use it directly, as they do with oxygen and carbon dioxide. This is because the triple bonds between nitrogen atoms in a N₂ molecule make it unreactive, while living organisms utilize relatively reactive nitrogen.[2] As a result, nitrogen is considered one of the essential limiting factors in the dynamics of our environment. However, the usable nitrogen in the atmosphere has increased and the nitrogen cycle altered significantly in the recent years due to human activities such as fertilizer production and fossil fuel consumption. To secure agricultural production, availability of resources, biodiversity, and functioning of ecosystems, and to minimize nitrogen’s effects on climate change, immediate actions need to be taken.

2. Nitrogen as a Useful Resource

With the fast development of technology in the recent decades, people have had increasing knowledge about the element nitrogen. We have discovered nitrogen to be a useful resource and have utilized nitrogen both in our everyday life and industries.

2.1. Uses in Pharmaceuticals

The utilization of nitrogen is a widespread method adopted by many pharmaceutical industries. For example, nitrous oxide is used as an anesthetic, and nitrogen itself can be used to preserve biological specimens such as sperm, eggs and blood.

2.2. Metal Production

Nitrogen is a key component to prevent oxidation in the process of metal productions. For example, in the production of stainless steel, nitrogen is required during the process to strength the steel and to prevent corrosion.
2.3. **Blanketing Agent**  
Due to nitrogen’s unique property as an inert gas, it is often used to separate unstable elements from the contact with air, to prevent possible hazardous reactions.

2.4. **Preservation of Food and Beverage**  
Because of nitrogen’s extremely low temperature, it is an effective agent in the process of food cooling and freezing. Other advantages also include the reduction of food damage, oxidation and worsen-flavors during long-distance transportation.

2.5. **Pressurizing Gas as Chemicals**  
During chemical processes, nitrogen can act as a propeller that helps liquids get through pipelines. It can also remove unstable organic chemical from the process.

2.6. **Fertilizers**  
Nitrogen is a key nutrient needed by the plants, as a result, adding nitrogen to the soil supplements nutrition deficiency. [3]

3. **The Nitrogen Cycle**  
As with other human-caused global change, before any further evaluation of the extensive human alteration on nitrogen’s increasing amount and its effects on the environment, it is necessary for us to first understand a major process involving nitrogen, and a process to secure all living organisms - the nitrogen cycle. The nitrogen cycle is a process of “fixing” nitrogen and the movement of nitrogen in various forms throughout the atmosphere. In order for plants and animals to successfully incorporate nitrogen into their cell function, nitrogen must be “fixed”, in other words, to be extracted from the atmosphere and to bond with hydrogen and oxygen to form inorganic compounds.[4] During the cycle, lightning accounts for some naturally occurring nitrogen: the electrical energy during a thunderstorm separate the nitrogen atoms in the atmosphere; the atoms then falls with rainwater to the soil, and acts as a natural fertilizer. While lightning transfers only a small portion of the total nitrogen amount, nitrogen fixation carried out by bacteria in the soil is the primary contributor. Bacteria such as those in the genus Rhizobium exists in a symbiotic relationship with the host plant, and they have the ability to transform the N2 molecules in the atmosphere into biologically available forms that is necessary in order for the plants to grow. Nitrogen produced by nitrogen-fixing bacteria is estimated to be 32-53 Tg/yr.[5] Animals which consume the plants and protein then become important nitrogen sources by passing the nitrogen through their waste. In addition, when the unconsumed plants decompose, they will transfer the nitrogen to the soil for reuse by other plants.[6]

4. **Fertilizers’ Contribution to the Nitrogen Cycle**  
The largest contributor to the sharply increasing nitrogen amount in the nitrogen cycle is N fertilizer. With knowledge about how beneficial the presence of nitrogen is to the development of crops, farmers eventually started to increase the amount of nitrogen when cultivating their land. However, resources available to farmer were very limited during the nineteenth and twentieth century. At first, farmers could only rotate lands between regular crops and those nitrogen-fixing plants, or add natural nitrogen sources like animal manure.

5. **Amount of Nitrogen Produced in N Fertilizers**  
According to research done by James Galloway and his colleagues, whose work on nitrogen has been published in BioScience, humans were creating about 15 teragrams (Tg) of nitrogen per year in the 1860s.[7] At this time, however, German scientists Fritz Haber and Carl Bosch developed the Haber-Bosch process, a method that combines hydrogen and nitrogen under high temperature and pressure to produce large amount of ammonia, which is the essential component of nitrogen fertilizers. The highly effective fertilizer dramatically impacted human’s ability to grow food, and it served as the "detonator of the population explosion".[8] Although Haber-Bosch process was able to boost crop production and the world population, it releases significant amount of chemically produced nitrogen into the atmosphere. Everyday, giant fertilizer factories around the world constantly perform the Haber-Bosch process to produce hundred million tons of fertilizers per year.[9] According to research lead by Peter
M. Vitousek, a scientist from the Department of Biological Sciences in Stanford University, Nitrogen fixation used in N fertilizers has increased exponentially from approximately zero in 1940. In addition, while the use of N fertilizers in developed countries has stabilized since 1970, applications in developing countries has been increasing significantly. The extra nitrogen that’s being spread on farmlands around the world and forced into the nitrogen cycle would eventually pose a threat to the balance and stability of many of Earth’s ecosystems.

6. Fossil Fuel Combustion’s Contribution to the Nitrogen Cycle
The combustion of fossil fuel also contributes to the global reactive nitrogen load. It has long been known that burning fossil fuel releases nitric oxides into the air and leads to smog and acid rain, but the extent to which it impacts the environment has remained unclear in the past few decades. To further evaluate this issue, researchers from Brown University and University of Washington explored a new approach. In a study published in Science, these researchers were able to trace the nitrates back to its source: nitric oxide produced by burning fossil fuels. The study also analyzed nitrogen isotopes found in nitrates from a Greenland ice core, and concluded that the ice core contains nitrates from about 1718, which corresponds to the beginning of the Industrial Revolution when fossil fuel came into view. “What we find is there has been this significant change to the nitrogen cycle over the past 300 years,” said Meredith Hastings, assistant professor of geological sciences at Brown and the paper’s lead author. “So, we’ve added this new source — and not just a little bit of it, but a lot of it.” The combustion of fossil fuel transfers about 20 Tg of reactive nitrogen from natural storage to the atmosphere each year.[10]

7. Total Amount of Nitrogen Injected by Human
According to Figure 1, a graph from a technical report published in Issues in Ecology in 1997, led by professor Peter Vitousek and his colleagues, other sources generates reactive nitrogen as well. For example, burning of biomass—combustion of organic matters—transfers more than 40 Tg each year; the turning of forests and grasslands into agricultural use converts 20 Tg per year; draining wetlands allows organic materials in the soil to oxidize, which mobilizes 10 Tg/yr or more. Although these sources seem rather insignificant, with all of them function at the same time, there can be dramatic impacts. In fact, human activities inject around 140Tg in total into the nitrogen cycle per year.[11]

![Figure 1. Amount of nitrogen injected into the nitrogen cycle by human activities](image)

8. Impacts on Plants
It is undeniable that the industrial uses of nitrogen have brought a series of advantages to our society, but as nitrogen level continue to rise, it poses a threat on agriculture, terrestrial and aquatic ecosystems, and human health. To begin with, large amount of nitrogen fertilizers can have negative effects on soil health, and can lead to decreased plant diversity. A team of scientists lead by Samuel M. Simkin studied more than 15,000 sites in the United States, and found that nitrogen deposition exceeded critical loads for loss of plant species richness in 24 percent of the sites. The result highlights that the overuse of nitrogen is affecting plant diversity across the United States.[13]

9. Impacts on Aquatic Ecosystems and Drinking Water
Furthermore, nitrogen produced by human activities is dramatically affecting the aquatic ecosystems. When nitrogen level rises in water, it often leads to algae overgrowth, which would harm water quality, food resources and habitats. When algae die and decompose in the water, the amount of organic materials increase. Oxygen is often required during this process, and the decreasing level of oxygen in water will threaten aquatic life. In addition, high reactive nitrogen level can also infiltrate drinking water, as soluble nitrogen from fertilizers and animal gets into rivers, streams and underground water. Groups such as children or the elderly will be exposed to potential diseases when come in contact with polluted water or aquatic organisms. For example, high nitrate concentration can cause methemoglobinemia, also called “blue baby disease”, due to nitrate ions weakening blood’s ability to transfer oxygen. In fact, scientists have also found connections between nitrate and various cancers and reproductive problems.

10. Impacts on Climate Change
Excessive nitrogen produced by human activities also has a great impact on the atmosphere and is connected closely to climate change. Different forms of nitrogen in the atmosphere include: N2O formed by nitrogen-fixing organisms, NOx produced by burning fossil fuel and biomass, and NH3 emitted by N fertilizers. NOx and NHx (NH3 and NH4+) are able to accumulate in the troposphere, but they cannot return to the form of N2. As a result, nitrogen in the form of NOx and NHx in the atmosphere returns to ground level eventually. Combined with the volatile organic carbon compound, increasing NOx level will lead to increased ozone concentration, and enhance the greenhouse potential of the atmosphere. In addition, N2O acts as a potent greenhouse gas as well, with each molecule absorbing outgoing radiation as much as 200 times more than carbon dioxide. Although reactive nitrogen increases ozone concentration in lower altitudes, it actually destroys ozone in higher altitudes. What happens in the stratosphere is that ultraviolet light breaks N2O apart, and forms NO molecules, which acts as a catalyst to break down the ozone layer. Unfortunately, destroying the ozone layer allows more ultraviolet light to enter the surface of the earth, and as a result, worsen the greenhouse effect.

11. Conclusion
To sum up, human activities have been altering the nitrogen cycle in a significant way. Although the application of nitrogen has brought unprecedented improvements to our society, it’s overuse can have serious consequences. So, it is necessary for us to understand both side of the issue and to act wisely.

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