Acta Ecologica Sinica 29 (2009) 130–135

Contents lists available at ScienceDirect

Acta Ecologica Sinica

journal homepage: www.elsevier.com/locate/chnaes

Human influences on mobility of nitrogen in the environment: Needs for research and management

S.K. Tripathi *

Department of Forestry, Mizoram University, Aizawl 796 009, India

ARTICLE INFO

Keywords:
Biogeochemistry of nitrogen
Anthropogenic nitrogen fixation
Nitrification and denitrification
Isotopic analysis
Land-use change

ABSTRACT

Nitrogen (N) cycles through air, water and soil and plays an important role in the synthesis of complex N compounds in all forms of life on the planet earth by combining with carbon, hydrogen and oxygen (O). Besides, natural fixation of N by microorganisms, advertent and inadvertent fixation of N by human activities (e.g. landscape transformations, fossil fuel burning and use of N in agricultural fields) are altering the global cycle of N. As a result of human activities, N enters in water bodies (e.g. streams, estuaries and coastal regions) making them hostile for aquatic life and contaminates ground water (used for drinking) through nitrate (NO_3^-) leaching which causes a number of health problems to human beings and animals. Hence, reduction in level of NO_3^- in water bodies and ground water is a prerequisite that can be met through sustainable management of natural and modified ecosystems. More specifically, agricultural management practices need to be better designed to synchronize the availability of NO_3^- with that of the crop N demand. These management goals can be achieved by thorough understanding of the origin and fate of N, by using isotopic analysis of N and O in NO_3^-, which can provide the best management options for N in the environment. Overall, an integrated approach would be required to limit N production/use and release to prevent critical environmental limit being exceeded.

1. Introduction

Nitrogen (N) cycles naturally through air, aquatic and soil by the processes of fixation, nitrification and denitrification and facilitates synthesis of essential N compounds such as amino acids, proteins, ammonium (NH_4^+) or nitrate (NO_3^-). Bulk (78%) of N is present in the atmosphere in tightly bound pairs as N_2 that can not be used by living beings. Most plant and animals need the reactive form of N that is bonded with carbon (C), hydrogen or oxygen (O) in the form of amino acids, NH_4^+ or NO_3^-. There are few N fixing bacteria including cynobacteria and specialized bacteria genus *Rhizobium*, which make symbiotic association with leguminous plants like peas, beans and alfalfa, and free living soil bacteria which are responsible for converting atmospheric N. The quantum of N fixed each year by natural nonagricultural organisms is believed to be with a minimum of about 100–300 Tg of N on the land surface [1]. Besides, natural phenomenon like lightening fixes about 3–10 Tg of reactive N each year. The energy generated by lightening convert O and N to nitric oxide (NO), which oxidizes to N dioxide (NO_2^-), then to nitric acid (HNO_3). This HNO_3 is carried to ground within few days by rain, snow, or other atmospheric depositions [2].

In early twentieth century, the agricultural N fixation by legume cultivation and naturally occurring fertilizer such as manure were responsible for producing 15 Tg of reactive N per year [1]. At the same time, German Scientist Fritz Haber and Carl Bosch discovered the catalytic process to convert non reactive atmospheric N to ammonia that forms the base of N fertilizer. Currently, this process is producing about 100 Tg of reactive N each year on global basis that is used as N fertilizer and the food grown with this fertilizer feeds about one-third (~2 billion) of the world population [3]. The human induced production of reactive N is closely correlated with increase in human population and is estimated to be about 170 Tg N per year [1]. The global use of N fertilizer is increasing at a rate of about 15 Tg per year.

According to Galloway et al. [1], the largest production of fertilizer N (ca. 100 Tg N per year as of 2000) is made by human activities. In addition, about 40 Tg of N is being fixed per year by N fixing crops (e.g. legumes), followed by agricultural expansion (conversion of natural forests and grasslands) 40 Tg of N and fossil fuel combustion about 20 Tg of N. Currently, Asia, Europe and North America account for almost 90% of human generated reactive N. These activities have considerably altered the global cycle of N by increasing both the availability and the mobility of N over the large regions of the planet earth [4–6]. The mobility of N refers

* Tel.: +91 389 2330394; Mob: +91 9436 353773; fax: +91 389 2330416.
E-mail address: sk_tripathi@rediffmail.com
URL: http://sktripathi_13@yahoo.com

1872-2032/$ - see front matter © 2009 Ecological Society of China. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.chnaes.2009.05.009

that the application of N occurs locally but its influence spreads regionally and ultimately globally [7,8]. Human-induced transfer and transport of N alters the global N cycling and information on retention and transformation of N in the environment (e.g. atmosphere, terrestrial and aquatic) is scanty.

The additions of N as NH_4^+ and NO_3^- have both quick beneficial effects on the productivity of agricultural crops and long-term environmental consequences like increasing rate of N input in natural terrestrial ecosystems, enhanced leaching of NO_3^-, loss of soil nutrients (e.g. Ca and K), acidification of soils and water bodies, contamination of ground water and transfer of N to estuaries and coastal oceans [9,10,5,6]. In European countries, particularly in the Netherlands and Germany natural and modified ecosystems are world's most saturated ecosystems because of N additions. In the coming 50 years the developing countries are supposed to face increased N related problems due to their dependence on N fertilizers, rising population densities and adoption of gasoline powered vehicles. In general, N additions may cause decline in the biodiversity and adverse effect on interactions among the closely associated animals and microbes in terrestrial ecosystems [11–14], would adversely affect the fish population in the estuarine and coastal ecosystems [6,15] and contaminate ground water that causes several diseases to human being.

As N cycle involves a set of complex processes like nitrification, denitrification and volatilization at different levels and so, it becomes difficult to quantify its retention, transformation and source at landscape scale. The distinction between the natural and anthropogenic N source has also become difficult to quantify [16] because of the identification of the N source and its flow path within the environmental reservoirs. To overcome this problem, recently isotopic technique has been successfully used in a number of case studies to identify N sources and to describe N transformations in terrestrial and aquatic ecosystems [17–20].

This paper describes the mobility of N in the environment (i.e. air, water and soil) and the use of isotopic elemental analysis of N and O to detect the origin and fate of N generated by different anthropogenic activities. Also, suggests future research needs and options for N management in the environment.

2. Human influences on N transformation and transport

Biogeochemical cycle of N allows this element to be used and reused infinite times between sources and sinks along a well-established pathway. For instance, the bulk atmospheric inactive N_2 is being transported to the soil mainly through the process of N-fixation. The global N cycle is being perturbed by the humans via fossil fuel combustion, mineral fertilizers and live stock manures. All provide major sources of reactive N leading to cascading effects as the N is transported and transformed within the environment [5,21,22]. Huge quantity (ca. 260 Tg) of atmospheric N is being converted to land surface each year [23]. Mean global efficiency of plants to absorb N (predominantly as NO_3^-) from the soil and to convert it into complex compounds (e.g. amino-acids and proteins) is only about 50% [24] which goes to the animal body by feeding and the rest is lost through run off and leaching (Fig. 1). After the death of plants and animals bacteria change the organic compounds into NO_3^- or NO_2^- and finally return to the atmosphere by the process of denitrification. The two processes, fixation and denitrification brought about the balance of N in the environment in the pre-industrial era as evident from the consistency in nitrous oxide (N_2O) records [25].

In recent years, enhanced anthropogenic N fixation is responsible for the conversion of huge amount of N from atmosphere to the land. As a result denitrification process, conversion of fixed organic N into inorganic gaseous form, is increasing to convert these N

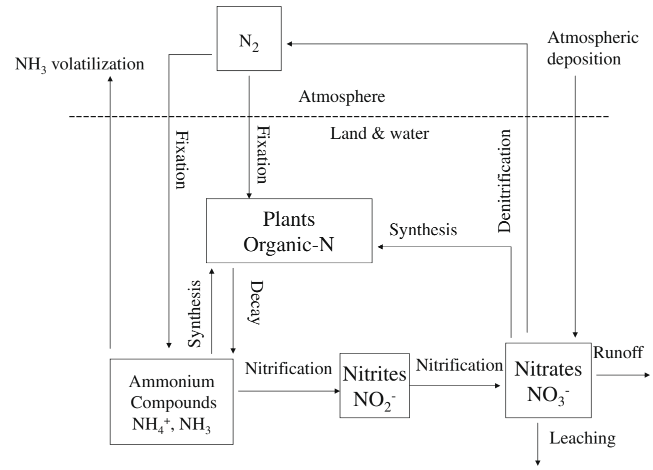

Fig. 1. Diagrammatic representation of N cycling in the environment. Boxes show the pools of different forms of N in the environmental components and arrows depict the transfers of N from one component to other through certain processes.

back into the atmosphere which in turn enhancing the environmental N loading as NH_x (NH_3 and NH_4) and NO_x ($NO + NO_2$) in the earth ecosystems. This phenomenon is now considered as the new challenge for the environmentalist to quantify and understand the global threat of N deposition. Most of environmental N loading impacts have been reported in the European and North American ecosystems [14]. Developing countries are emerging as the major emitters of N because of increasing population and rapid industrialization and it is estimated that by 2020 these regions will account for more than half of the global anthropogenic fixation of N [26,12].

According to mass balance, less than 30% of the anthropogenic N inputs to large watersheds is exported to the oceans through surface runoff [10,19] and more than 70% of human controlled N inputs is stored, denitrified or volatilized in the watersheds [20]. The relative importance of the N retention and transformation mechanisms is difficult to quantify on watershed scale and global scale because of their spatial and temporal variations [27]. Hence, the information on regional N budget at landscape scale would be important to make a global budget of N retention and transformations in different environmental reservoirs.

Landscape transformations are occurring throughout the world. Conversion of natural forests to savannas and croplands is increasing rapidly in dry tropical region in India and these practices are dramatically increasing the loss of NO_3^- to the riverine ecosystems. Natural ecosystems like forests are considered to be N conservative in the sense that N recycles within plant-soil system efficiently and thus the losses of NO_3^- from soil are minimal. When the forests are converted to the agricultural fields, the loss of NO_3^-, a highly soluble form of N, increases dramatically. NO_3^- washed from the agricultural fields is one of the major causes of eutrophication in freshwater bodies, estuaries and coastal regions. NO_3^- also reaches the shallow ground water through leaching and exceeds the drinking water standard under agricultural fields in different parts of the world. The information on this aspect is highly limited and deserves an immediate attention. Such information on different ecological regions of Asian countries like India and China, together holding about 40% of the world's population, will help in establishing a model of the biogeochemistry of N in changing environment.

Nitrification is the key processes in N cycle that plays an important role in natural and managed ecosystems by regenerating N available to plants. Forest ecosystems are complex and believed to have tight coupling between available N, especially NO_3^-, and plant roots and microflora so that the chances of NO_3^- loss are