International Journal of Environmental Sciences Vol. 3 No.1. 2014. Pp. 5-10

Full Length Research Paper

Perturbations in Global Nitrogen Cycle - Causes and Consequences: A Review

S.K. Tripathi
Department of Forestry, School of Earth Sciences and Natural Resources Management, Mizoram University Aizawl-796004

Abstract
Human activities like production of synthetic nitrogen (N), cultivation of rice-legume and the burning of fossil fuel have doubled the rate at which inert atmospheric N is 'fixed' on the land in the active form that can be used by living organisms. These activities have significant contribution to support the adequate standard of life for feeding more than 7 billion people on the planet earth. Consequently, the environmental disruptions caused by a planetary overload of N have now been realized as an emerging global problem in this century. Too much of fixed N can warm the earth's atmosphere, can damage the ozone layer in the stratosphere and can make the species vanish from the earth. More specifically, continuous input of N in terrestrial ecosystems can cause N saturation and many structural and functional changes like mobility of biota and physiological traits of species, and alter soil processes in the ecosystems. Further, the excess of N contaminates the ground water through leaching that has serious concern for human health, and enters aquatic and marine ecosystems and makes them hostile for their inhabitants. N management options have been suggested through an integrated approach to limit N production and its use so that the critical environmental limit should not exceed.

Key words: *Global nitrogen cycle, terrestrial nitrogen fixation, environmental nitrogen loading, terrestrial ecosystem, nitrogen management*

Introduction

Nitrogen has been discovered as an element in late 18th century and represented by letter 'N'. The phenomenon of biological N fixation and the role of N in plant productivity have been discovered in the late 19th century (Galloway and Cowling 2002). This has necessitated the world to synthesize reactive N that could be used as fertilizer to ensure crop production to feed the growing population. As a result, at the end of the 20th century the anthropogenic nitrogen fixation exceeded the natural terrestrial nitrogen fixation. No doubt that synthetic N has fulfilled the growing demand for food of more than 7 billion people on this earth. But as a result of N production and fossil fuel burning the reactive N has become a serious environmental threat to our ecosystems and society in the 21st century (Vitousek et al 1997, Sala et al 2000, Singh and Tripathi 2000, Phoenix et al. 2006, Tripathi 2009). In this paper the author has described brief scientific information related to N and their significance to the society and the major environmental consequences of N deposition to our ecosystems and societies in the present century. Further, the options for N management in the environment have been suggested. The outcome of this paper will be useful for making science policies that can be beneficial for managing N in the environmental and to overcome with the possible consequences of enhanced environmental N loadings on the ecosystem and the society.

Brief history of element nitrogen: A Walkthrough

Element N was discovered in the late 18th century through the work of several chemists from different countries and was named 'nitrogen' (represented by N) by a French Scientist, Jean Claude Chaptal in 1970 (Smil 2001). Its role in crop production practice was not recognized until the mid-19th century. In late 19th century von Liebig (1803-1873) has developed the theory of nutrient limitation in plant productivity and at the end of this century, Hellriegel (1831-1895) and Wilfarth (1853-1904) discovered the process of biological N fixation by microbial communities (Galloway and Cowling 2002). At around < 50 years after the realization of N as an essential element for plants and animals it was understood that the growing demand for food as result of increasing human population would be exceeding the known sources of reactive N (Galloway and Cowling 2002). In 1898, Sir William Crookes, presidents of the British Association for the Advancement of the Science, stated: "All England and all civilized nations stand in deadly peril of not having enough to eat" due to increasing demand for food and the lack of available N. This understanding has necessitated the world to look for the alternatives to synthesize reactive N that could be used as fertilizer to ensure crop production to feed the growing population.

At the beginning of 20th century (in 1913), Fritz Haber, a German physical chemist, has discovered a catalytic process (termed the Haber Ammonia Process or Synthetic Ammonia Process) for directly synthesizing ammonia from atmospheric hydrogen and N, and was awarded a Noble Prize for Chemistry in 1918 for this land mark achievement. Later, Carl Bosch an industrial chemist translated the method into a large-scale process at high-pressure using a catalyst and won a Nobel Prize in 1931 jointly with Friedrich Bergius for high-pressure studies.

The Haber-Bosch process has tremendous capacity to produce reactive N, from seemingly unlimited source of atmospheric N_2 that could be used for food production. After the invention of this process, the human population started to grow exponentially as function of N production. It is estimated that still today, more than half of the food produced globally is as a result of the use of N fertilizer synthesized from the Haber-Bosch process (Smil 2001). Needless to say that Fritz Haber was awarded a prestigious Noble Prize in 1918 for this outstanding discovery that made a significant contribution in Science and services to humanities. If the contribution of Haber process is taken into account for serving the world human population in 20th century, it can be definitely said that this discovery was the 'Noble of the Nobles' prizes given in the 20th century. The consequences of synthesis of N fertilizer have arisen just within the 100 years and currently the human alteration of the global N cycle is one of the major environmental problems confronting society (Vitousek et al 1997). Professor James Galloway of the University of Virginia has mentioned 'Reactive nitrogen: Too much of a good things?' (Galloway et al 2002). This suggest that what appears to be a breakthrough invention at one time point may result into a major ecological consequences at later point in time.

Nitrogen cycling in the environment

N accounts for 78% of the atmosphere as elemental di-nitrogen (N_2), which is in the un-reactive (inert) form and is not suitable for the growth and metabolism of almost all living organisms except cyanobacteria. Biological N cycle begins with the fixation of this N_2 to NH_3/NH_4 ions (a reactive form of N) in the soil. Symbiotic *Rhyzobia* (i.e. legume bacteria), non-symbiotic free-living bacteria (i.e. A*zotobacter*, C*lostridium*) and blue green algae (i.e. *Anabina, Nostoc*) are mainly responsible for this process of conversion of un-reactive form of N into reactive form (Fig. 1). One part of this form of NH_3/NH_4 is assimilated in biomass by the process of ammonia assimilation and another part is converted into NO_2^- or NO_3^- through nitrification. Part of this NO_3^- is t aken up by biomass and the part is lost through leaching. Through the process of denitrification this reactive form of N (NO_2^- or NO_3^-) goes back into atmosphere as N_2 or N_2O by reduction process. 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 N_2O records (Ayers et al. 1994).

Biogenic N_2 and nitrous oxide (N_2O) are produced in the soils of terrestrial ecosystems through a wide range of processes such as decomposition, mineralization, nitrification, denitrification etc. Of these processes, nitrification and the denitrification are the important for N_2O production, whereas the decomposition process does not directly produces N_2O but it provides a substrate for the two above processes. Denitrification is a reduction process in which nitrate (NO_3^-) is converted into nitrite (NO_2^-) then nitric oxide (NO) and nitrous oxide (N_2O) and finally the N_2 molecule is produced. Nitrification is the process of biological oxidation of conversion of NH_4^+ to NO_2^- and NO_3^-.

At present biological N fixation coupled with anthropogenic fixation involves huge amount of N conversion from the atmosphere to the land. As a result denitrification process is increasing to convert these N 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 ecosystems. This increase in environmental N loading may have several consequences on the structure and functioning of these ecosystems, which in turn will affect the human beings. Thus an establishment of N budget is needed to understand the options for efficient management of N and to mitigate its future environmental impact.

History of N conferences to explore, identify and solve N related problems

The environmental consequences of N production have been recognized for more than 30 years (Delwiche 1970). But during the last one and a half decade the increased international attention has been focused on the complexities of human alteration of the N cycle and on how to optimize the production of food and energy while minimizing the environmental consequences (Galloway et al. 2002, Tripathi 2009). In this respect, the first international N conference was held in March 1998 in The Netherlands with a view to document the extent to which the world's natural resources and the environmental systems are responding to reactive N enrichment and emphasize to work together to solve N related problems. The second international N conference was held in October 2001 in USA to provide the update on N science and policy with a focus on Asia and to create an international N initiative (INI), which was established in 2002 to assess knowledge on N science, to identify problems and to implement solutions through regional centers worldwide. Consequently, the third N conference was held in Nanjing, China in October 2004 to explore expected increase in the generation of the largest quantity of reactive N in the Asian continent and its great potential for the further increase in the magnitude to fulfill the growing demand of food and energy. In the last, Nanjing declaration calls governments to optimize N management at different scales by: further assessment of N cycle, increase N use efficiency and effectiveness in agriculture production and energy use and to develop solutions to reactive N problems (both excess and lack).

The 4th International N conference was organized in Brazil in 2007 under the auspicious INI to focus on Latin America with aim to discuss both 'too little' and 'too much' N and full session was dedicated to industry. Some of the main issues addressed in the conference were: biofuel production and N_2O emissions, animal production and alterations of the N cycle, indirect impacts on human health of reactive N losses, N fertilizer use and poverty alleviation, policy responses (assessment needs, policy instruments). The 5th International N conference was held in Delhi in 2010 under the auspicious INI to work out all aspects of N in maximizing sustainable food production and diminish negative effect of N on human health and environment. The 6th International conference will take place in November 2013 in Uganda, South Africa with four major themes: a) N in context of food production, b) N impacts on human health and ecosystem health, c) management approaches in too much and too little N regions, and d) integrated assessment of N dynamics at spatial and temporal scales.

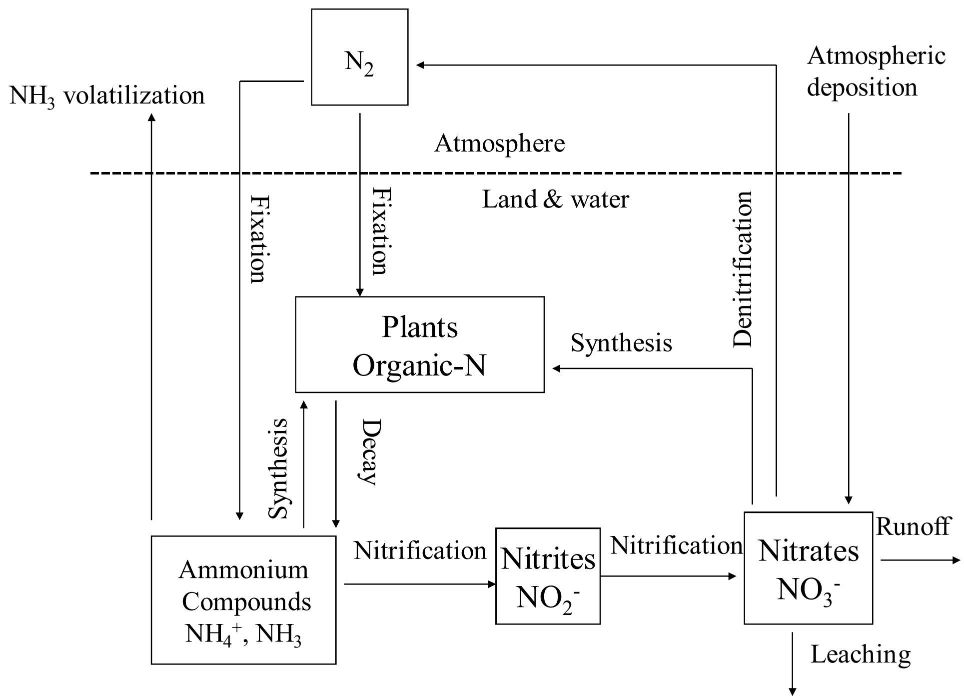

Fig. 1. General diagram showing the N cycling in the environment. Boxes show the pools of N in the environmental components and arrows show the transfers of N from one component to other through certain processes.

Nitrogen transformations in the environment

Human activities like industrial N fixation, the distribution and inadvertent fixation of N during fossil fuel combustion, and rice-legume cultivation has substantially increased the quantity of N fixed in terrestrial ecosystems (Galloway et al. 1995, Vitousek et al. 1997, Matson et al. 1999). From 1890 to 1990, the global rate of N fixation by anthropogenic activities increased from ca. 15 Tg N yr^{-1} to ca. 140 Tg N yr^{-1}, whereas the natural terrestrial biological nitrogen fixation rate decreased from ca. 100 Tg N yr^{-1} to ca. 89 Tg N yr^{-1} during the same period (Galloway and Cowling 2002). During this period, most of the countries throughout the world have transformed from bio-fuel to fossil fuel economy for their energy production. This increase in the use of fossil fuels resulted in the increase in the NO_x emissions from ca. 0.6 Tg N yr^{-1} in 1890 to ca. 21 Tg N yr^{-1} in 1990 (Levy et al. 1999). N fixation rates in Asian continent are of much interest because of expected increase in human population. Zheng et al (2002) have outlined a case study of Asian N cycling and shown that the anthropogenic reactive nitrogen in Asia dramatically increased from ca. 14.4 Tg N yr^{-1} in 1961 to ca. 67.7 Tg N yr^{-1} in 2000 and is likely to be 105.3 Tg N yr^{-1} by the year 2030.

Most of the anthropogenic N can be expected to accumulate in the different ecosystems. The distribution of fixed N within and between terrestrial ecosystems has also been enhanced as a result of deforestation, biomass burning, wetland drainage, and other processes (Vitousek and Matson 1993, Vitousek et al 1997). As a consequence increased depositions of N have been noticed unevenly in different parts of the world. At present, atmospheric concentrations of both oxidized and reduced reactive N vary strongly with the region (Chameides et al. 1994), but are highest in locations around and down wind from the major source areas such as the northeastern U.S., Western and Central Europe and East Asia. More specifically, N deposition is more concentrated near the industrial regions and the areas where intensive agriculture is widespread (Townsend et al. 1996, Matson et al 1999). Enhanced N depositions in the ecosystems have been reported to considerably affect the ecosystem properties such as biodiversity, trace gas exchange, cation leaching and functioning (Howarth et al. 1996, Vitousek et al. 1997, Singh and Tripathi 2000, Tripathi and Singh 2001), and leading to 'N saturation' in the ecosystems (Agren and Bossata 1988, Aber 1992). N saturation is a point where inputs of N exceeds the biological demand for N within the ecosystem and thus, the system loses its ability to retain N.

Environmental consequence of increasing nitrogen deposition

Increased environmental N loading has been reported to drastically alter the structure and functioning of different ecosystems around the world (Vitousek et al 1997, Sala et al 2000, Singh and Tripathi 2000, Suding et al. 2005, Phoenix et al. 2006) which in turn will affect the ecosystem services to the human beings in the coming decades. The ecological consequences of biodiversity loss have aroused considerable interest and controversy during the past decade. Major advances have been made in dealing with the relationship between species diversity and ecosystem processes, in identifying functionally important species, and in revealing underlying mechanisms (Loreau et al 2001). A major task ahead among the environmentalist is to understand how species diversity and ecosystem processes and their interactions will change as a result of increasing N depositions which is occurring world over at unprecedented rate.

Likely impact of environmental N loading on natural and modified ecosystems

During the past few decades, increasing additions of N as NH_x (NH_3 and NH_4), NO_x ($NO+NO_2$), nitrate and nitrite into different terrestrial ecosystem of the world have been recorded at unprecedented rate (Vitousek et al. 1997). This addition of N is supposed to affect the global biochemical cycles, land fertility level and enhancing the mobility of the biota, and all these have lead to changes in the ecosystem unexpectedly (Chapin et al. 2000). Magnitude of this change will be associated with its influence on ecosystem processes and the societies for the use of natural resources. The changes in ecological diversity would be one of the most important global change phenomenon. Change in the global biodiversity as a result of N deposition has been considered as the third most important driver of change in majority of the ecosystems after land use and climate change (Sala et al, 2000). However, the response of different drivers may vary in different ecosystems depending on the availability of N in that particular ecosystem.

According to Sala et al. (2000) the N deposition has been linked to high rate of change in the diversity in all terrestrial biomes with the exception to the arctic and tropical regions with the former projected to have negligible changes and the later low amount of changes. Prediction of low changes in the tropical biodiversity is mainly based on the major generalization that tropical ecosystems are phosphorus (P) limited in contrast to temperate which are limited to N. According to Vitousek (1984) the biodiversity in the deserts and the tropical forest may respond least to N deposition because the plant growth is strongly limited by water and P availability, respectively. Sala et al (2000) have generalized that Grassland, Savanna and Mediterranean systems have intermediate impact on biodiversity due to N loading. If we consider the recent report that the N have a more profound effect than phosphorus on determining the ecosystem structure and functioning in dry tropical forests and savannas ecosystems in Vindhyan region in India (Singh and Tripathi 1999; Singh and Tripathi 2001; Tripathi 2002, Tripathi 2009). It would be an important to understand the crucial role of N loading in changing the biodiversity patterns in terrestrial ecosystems with emphasis in tropical region.

The changes in the ecosystem diversity as a result of the enhanced N deposition and altered soil processes have been considered on the basis of the facts described above. In a brief, an increase in the soil N availability due to faster N-mineralization will lead to an increase in the density of the species (mostly N loving species) that were earlier restricted due to the limitation of N. Fast growth of such species will adversely affect the slow growing plants adapted to N poor environment due to increased soil N availability and competitive ability of fast growing species. The influence of all ecosystem processes is expected to vary from one ecosystem to the other. In general the diversity is first expected to increase, due to invasion of N loving species if the replacement of N sensitive species are not at the same rate, and then decrease as result of the increased resource sharing by the dominant species and removal of species sensitive to N. In most of the cases the faster growing plants are not endemic to the ecosystem and are invaders. So the increase in the amount of N deposition in the ecosystems may lead to the replacement of local flora that may be endemic by the exotic species and may change the composition of whole ecosystem.

Likely impacts of enhanced nitrogen loading on human health and society

The inputs of mobile forms of N have beneficial effects on productivity of agricultural crops, whereas, it has several environmental consequences like increasing rate of N input in natural terrestrial ecosystems; increased concentration of oxides of N that lead to the formation of smog over large regions and enhanced leaching of nitrate that causes loss of other soil nutrients like Ca and K; it causes acidification of soils, streams and lakes in many regions; and it causes eutrophication of water by transfer of N through rivers to estuaries and coastal oceans (Schindler and Baylay 1993, Howarth et al. 1996, Vitousek et al 1997).

After entering the terrestrial ecosystems N may increase the quantity of organic carbon storage and may cause decline in the biodiversity in different terrestrial ecosystems and may also adversely affect the interactions among the closely associated animals and microbes (Sala et al. 2000, Singh and Tripathi 2000, Suding et al. 2005, Phoenix et al. 2006). Besides, when N enters the estuarine and coastal ecosystems it would alter the composition and functioning of these ecosystems, and would ultimately results in the decline of the fish population (Matson et al. 1999, Bohlke et al. 2004).

Further, N reaches the shallow ground water through leaching and exceeds the drinking water standard that causes several serious diseases to human being. It causes methamoglobinamia that loses the oxygen-carrying capacity of red blood corpuscles in babies and leads to their death. Other important health problems associated with nitrate toxicity in human beings are: oral, colon, rectum and gastrointestinal cancer (Peter 1998, Paul et al 1999); Alzheimer's disease (Tohgi et al 1998); multiple sclerosis (Govannoni G et al); non-Hodkins's lymphoma (Michal 1998). Nitrite and nitrate ions under various clinical conditions cause diseases like hypertension, infection, renal and cardiac disease, inflammatory diseases and so on. Besides, nitrate and nitrite cause methamoglobinamia and number of other diseases to different animals like pigs, rats cattle's, sheep, dogs, chickens and turkeys (Prakash Rao and Puttana 2000).

Management options for N in the environment

Nitrogen management options require understanding the basic factors that are responsible for the environmental N loading. Our efforts for producing more food to meet the growing demand of human population are dependent on increasing fertilizer and human energy. Thus, the basic factors as discussed above in brief would be: the need for more food; the change in food patterns, especially in developing countries (to more meat, more luxurious food rich in proteins) and the need for more energy. This will vary from place to place. Thus, an integrated approach is required to limit N production and its use to prevent critical environmental limit being exceeded. This integrated N approach can be further extended to link with carbon and other nutrients to make it an integrated environmental approach.

Nitrate export from agricultural fields can be significantly reduced through various management options like cover crops, mixed cropping, use of nitrification inhibitors or controlled release fertilizers, site-specific crop management, variable rate of application, proper scheduling of irrigation, sprinkler or drip irrigation with fertigation, banding and split application, foliar application and so on (Rao and Puttana 2000). Water table adjustment is also practiced to reduce the level of nitrate discharge by increased denitrification and maximize plant uptake. Enhancing fertilizer N use efficiency by ensuring measures such as balanced application of nutrients, proper coordination of N and irrigation management can substantially control the leaching of nitrate N beyond crop rooting zone (Tandon 1992). Nitrate discharge from agro-ecosystems can maximally be controlled by the following practices: (a) by increasing crop complimentarity, in space and time, in resource use; (b) enhancing crop N use efficiency; (c) by optimizing application of N fertilizer to particular site; and (d) by enhancing synchronization of N availability with that of crop N demand.

Conclusion

The global change processes particularly N deposition in natural ecosystems has been considered as one of the important factors to affect the biodiversity and ecosystem functioning in many ecosystems. Because the N has been widely known to play a crucial role in plant growth and most of the natural ecosystems are limited by the availability of N in the soil. Thus, it is expected that the increased N deposition in natural ecosystem will enhance the soil N availability and in turn dramatically affect the ecosystem diversity as a result of increased abundance of N-loving species within and the removal of N-sensitive species from the ecosystem. Further, N loading will change the interaction among the species and in general the possibility of invasion with increase in the dominance of a few species with an overall decrease in species diversity resulting in a modification of complex natural communities to relatively simple one in the future. In addition, the simple community may have different species characteristics that may further affect the ecosystem services and the society. Excess nitrate washed from the agricultural fields is one of the major causes of eutrophication in estuaries and coastal regions. Nitrate also reaches the shallow ground water through leaching and exceeds the drinking water standard under agricultural fields in different regions. Enhanced nitrate in drinking water are causing hypoglaxamia or blue baby syndrome in human beings. N management options are needed to optimize N production systems and demand.

References

Agren, G.I., Bosatta, E. 1988. Nitrogen saturation of terrestrial ecosystems. Env. Poll. 54, 185-197.

Ayers R U, Schlesinger W H, Socolow R H. 1994. Human impacts on the carbon and nitrogen cycles. In: Socolow R H, Andrew C, Berkhout R, Thomas V eds. Industrial ecology and global change. Cambridge University, Cambridge, MA. 121-155.

Bohlke J K, Harvey J W, Voytek M A. 2004. Reach-scale isotope tracer experiment to quantify denitrification and related processes in a nitrate-rich stream, mid continent Unites States. Limnol. Oceanograph*,* 49: 821-838.

Chameides, W.L., Kashibhatla, P.S., Yienger, J. and Levy II, H. 1994. The growth of continental-scale metro-agro-plexes, regional ozone pollution, and world food production. Science 264: 74-77.

Chapin III, F.S., Zavaleta, E.S., Eviner, V.T., Naylor, R.L., Vitousek, P.M., Reynolds, H.L., Hooper, D.U., Lavorel, S., Sala, O.E., Hobbie, S.E., Mack, M.C. and Diaz, S. 2000. Consequences of changing biodiversity. Nature, 405, 234-242.

Delwiche C.C. 1970. The nitrogen cycle. Sci. Am. 223: 137-146.

Galloway J.N., Cowling E.B., Seitzinger S.J., Socolow R. 2002. Reactive nitrogen:

Galloway, J.N. and Cowling, E.B. 2002. Reactive nitrogen and the world: 200 years of change. *Ambio*, 31(2), 64-71.

Galloway, J.N., Schlesinger, W.H., Levy H. II, Michaels, A., Schnoor, J.L. 1995. Nitrogen fixation: atmospheric enhancement-environment response. Global Biogeochem. Cycles 9, 235-252.

Govannoni G, Heales S J R, Siver N C, O'Riorden J, Miller R F, Land J M, Clark J B, Thompson E J. 1997. Raised serum nitrate and nitrite levels in patients with multiple sclerosis. J Neurol Sci, 145: 77-81.

Howarth, R.W., Billen, G., Swaney, D., Townsend, A., Jaworski, N., Lajtha, K., Downing, J.A., Elmgren, R., Caraco, N., Jordan, T., Berendse, F., Freney, J., Kuderyarov, V., Murdoch, P., Zhaoliang, Z. 1996. Regional nitrogen budgets and riverine N and P fluxes for the drainages of the North Atlantic Ocean: Natural and human influences. Biogeochemistry 35 (1), 75-140.

Levy, H., II, Klonecki, A.A. and Kashibhatla, P.S. 1999. Simulated tropospheric NO_x : Its evaluation, global distribution and individual source contributions. J. Geophysical Research 104, 26 279- 26 306.

Loreau, M., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J. P., Hector, A., Hooper, D. U., Huston, M. A., Raffaelli, D., Schmid, B., Tilman, D., Wardle D. A., 2001. Biodiversity and ecosystem functioning: current knowledge and future challenges. *Science* 294, 804-808.

Matson, P.A., McDowell, W.H., Townsend, A.R., Vitousek, P.M. 1999. The globalization of nitrogen deposition: ecosystem consequences in tropical environments. Biogeochemistry 46, 67-83.

Michal F D. 1998. A population based case control study on the association between nitrate in drinking water and non-Hodkin's lymphoma, Jones Hopkins University, USA, 285.

Paul K, Ritva J, Jan D, Timo H. 1999. Risk of colorectal and gastro-intestinal cancers International J Cancer, 80: 852-856.

Petter W J. 1998. The Lowa Women's Health, Univ Lowa, USA. 255.

Phoenix G K, Hicks W K, Cinderby S, Kuylenstierna J C I, Stock W D, Dentener F J, Giller K E, Austin A T, Lefroy R D B, Gimeno B S, Asmore M R, Ineson P. 2006. Atmospheric nitrogen deposition in world biodiversity hotspots: the need for a greater global perspective in assessing N deposition impacts. Global Change Biol., 12: 470-476.

Prakash Rao E V S, Puutanna K. Nitrates, agriculture and environments. 2000. Curr. Sci. 79: 1163-1168.

Sala O E, Chapin III F S, Armesto J J, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Hunneke L F, Jackson R B, Kinzig A, Leemans R, Lodge D M, Mooney H A, Oesterheld M, Poff N L, Sykes M T, Walker M, Wall D H. 2000. Global biodiversity scenarios for the year 2100. Science*,* 287: 1770-1774.

Schindler D W, Balay S E. 1993. The biospheres as an increasing sink for atmospheric carbon: Estimates from increasing nitrogen deposition. *Global Biogeochem. Cycles*, 7: 717-734.

Singh K.P. and Tripathi, S.K. 1999. Responses of terrestrial ecosystems to nutrient enrichment. pp. 327-350. In: Tandon, R.K. and Singh, P. (Eds.) Biodiversity Taxonomy and Ecology, Scientific Publisher (Jodhpur) India.

Smil V. 2001. Enriching the Earth. MIT Press, Cambridge, MAAber, J.D. 1992. Nitrogen cycling and nitrogen saturation in temperate forest ecosystems. Trends Ecol. & Evol. 7, 220-223.

Suding, K N, Scott LC, Laura G, Christopher C, Cleland E E, Gross K L, Milchunas D G, Pennings S. 2005. Functional- and abundance-based mechanisms explain diversity loss due to N fertilization. Proc. Nat. Acad. Sci., 102: 4387-4392.

Tandon H L S. 1992. Fertilizers, organic manures, recyclable wastes and bio-fertilizers. Fertilizer Development and and Consultation Organization, New Delhi. 148.

Tohgi H, Abe T, Yamazaki K, Murata T, Isobe C, Ishizaki E. 1998. The cerebrospinal fluid oxidized NO metabolites, nitrite and nitrate, in Alzheimer's disease and vascular dementia of Binswanger type and multiple small infarct type. Journal of Neural Transmission*,*105, 1283-1291.

Too much of a good thing? Ambio 31: 60-63.

Townsend, A.R., Braswel, B.H., Holland, E.A., Penner, J.E. 1996. Spatial and temporal patterns in terrestrial carbon storage due to deposition of fossil fuel nitrogen. Ecol. Applications 6, 806-814.

Tripathi, S.K. 2002. Impact of nutrient enrichment on plant biodiversity in a dry tropical forest and savanna ecosystems in Vindhyan dry tropical forest and savanna ecosystems. Report submitted to DST, New Delhi.

Tripathi, S.K. 2009. Human influences on mobility of nitrogen in the environment: Needs for research and management. Acta Ecologica Sinica 29: 130-135.

Tripathi, S.K. and Singh, K.P. 2001. Ecological responses of dry tropical forest and savanna ecosystems to nutrient enrichment. In: Environment and Agriculture: Biodiversity, Agriculture and Pollution in south Asia, pp. 150-157. Eds. P.K. Jha, S.K. Baral, S.B. Karmacharya, H.D. Lekhak, P Locoul and C.B. Baniya, Published by Ecological Society of Nepal.

Vitousek P M, Aber J D, Hawarth R W, Likens G E, Matson P A, Schindler D U, Schlesinger W H, Tilman D G. 1997. Human alteration of the global nitrogen cycle: Sources and consequences. Ecol. Appl.*,* 7: 737-750.

Vitousek, P.M. 1984. Litterfall, nutrient cycling, and nutrient limitation in tropical forests. Ecology 65, 285-298.

Vitousek, P.M., Matson, P.A. 1993. Agriculture, the global nitrogen cycle, and trace gas flux. In: Oremland, R. (Ed.) Biogeochemistry of Global Change: Radiatively Active Trace Gases. Chapman and Hall, NY, USA, pp. 81-105.

Zheng, X., Fu, C., Xu, X., Yan, X., Chen, G., Han, S., Huang, Y. and Hu, F. 2002. The Asian nitrogen case study. Ambio, 31(2), 79-87.