

Carbon and Nitrogen Cycling in Agroecosystems: An Overview



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Abstract Soil organic carbon (SOC) is the key constituent of soil organic matter (SOM). As a sign for soil health, SOC plays significant contributions to food production, extenuation, and variation to climate change. High SOM content delivers nutrients to plants and enhances water availability, both of which improve soil fertility and eventually enhance food production. Additionally, SOC enhances soil structural firmness by encouraging aggregate development which, together with porosity, warrants adequate aeration and water infiltration to support plant growth. Soils are also a source of greenhouse gas (GHG) emissions into the atmosphere. While the general effect of climate change on SOC stocks is very inconsistent according to the region and soil type, increasing temperatures and enhanced frequency of extreme events are likely to lead to enhance SOC losses. Global nitrogen fixation is the main contributor of the reactive nitrogen (Nr) to terrestrial and marine ecosystems, for which the anthropogenic activities are responsible. Majority of the conversions of anthropogenic Nr are on land within soils and vegetation. Emissions of ammonia (NH₃) and nitrogen oxides (NO_x) in the atmosphere lead to the productions of secondary pollutants such as ozone and other photochemical oxidants and aerosols (specially ammonium nitrate and ammonium sulfate). This chapter aims to deliver an outline to decision-makers and specialists of the key scientific details and information concerning the existing knowledge and knowledge gaps on carbon and nitrogen cycling in the agroecosystem.

Keywords Agroecosystem · Climate change · Greenhouse gas emissions · Nitrogen cycling · Soil organic carbon

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Abbreviations

BNF	Biological nitrogen fixation
C	Carbon
DOC	Dissolved organic carbon
FAO	Food and Agriculture Organization
GHG(s)	Greenhouse gas (es)
GWP	Global warming potential
HONO	Nitrous acid
N	Nitrogen
N ₂ O	Nitrous oxide
NH ₃	Ammonia
NH ₄	Ammonium
NO	Nitric oxide
NO ₂	Nitrogen dioxide
NO _x	Oxidized forms of nitrogen
NPP	Net primary productivity
N _r	Reactive nitrogen
PAN	Peroxyacetyl nitrate
SOC	Soil organic carbon
SOM	Soil organic matter
UNCBD	Convention of biological diversity at the United Nations

1 Introduction

The importance of carbon (C) and nitrogen (N) in agriculture and its wide-ranging implications to environmental aspects bring the C and N cycles to the centerpiece of agroecosystems, especially against the backdrop of climate change and its impacts on life on earth. While the C and N cycles are central to the earth's biogeochemistry in all kinds of ecosystems, the cycling of C and N in agroecosystems is of enormous importance due to the two elements' key status as major nutrients. Apart from being two key essential elements for plants, C and N are also key elements of greenhouse gases causing global warming. Agroecosystems are not only challenged by sustainable resource use but also by climate change, to which they themselves are contributors as well. Therefore, better understanding of C and N cycling in agroecosystems is essential to any possible improvements in functioning of agroecosystems.

Global N cycle is largely affected by human activities, as most of the fixed N comes from the anthropogenic activities, thus having vast environmental, agricultural, and health implications. For example, the huge production and consumption of synthetic fertilizers is causing groundwater pollution by the accumulation of nitrate and nitrite through leaching process. The excessive deposition of N forms in soils also causes environmental pollution through N₂O emissions, and the groundwater contamination poses serious threats to human health causing gastric cancer by

drinking contaminated water. A better understanding of key processes involved in N cycle and the contribution of each process as source or sink of N_2O can enable to improve agroecosystem management, and various options can be explored to ameliorate the negative effects of relevant anthropogenic activities.

Cycling of elements in the ecosystem is important for sustainability, in which the nutrient cycling is essential for living organisms on globe as the cycling prevents accumulation of elements, thus avoiding toxicity. Along with N cycling, the cycling of C is also of great importance as in recent decades both the C and N cycling have gained attention, because they are capable to produce greenhouse gases (GHGs). In C cycling, CO_2 and CH_4 gases have significantly contributed to increased atmospheric CO_2 and the global warming due to GHGs emission effects. Various ecosystem processes are responsible for GHG emissions, in which the release of CO_2 and CH_4 gases by plants and soil respiration is prominent. Therefore, recent research efforts are focusing on increasing the carbon sequestration rates as a mitigation strategy to global warming and most importantly to improve the soil health to sustain the soil microbiota and for increasing crop yields.

This chapter briefly outlines the key components and processes of C and N cycling in agroecosystems and presents the understanding of vital processes and their interrelationship involved in C and N cycling. Using this knowledge, management options and strategies can be employed to improve the anthropogenic activities responsible for negative effects due to the excessive N-inputs on the agroecosystem.

2 Soil Organic Carbon (SOC): A Crucial Component of Carbon Cycle

Soil organic carbon (SOC) is one of the major parts of global carbon cycle which basically involves in the cycling of C (carbon) from and between the soil, ocean, vegetation, and atmosphere. The SOC pool is estimated to store 1500 PgC in the upper layer of soil (FAO and ITPS 2015). The phonemical SOC reservoir is continually cycling with different molecular forms of C between various global carbon pools (Kane 2015). As CO_2 and CH_4 are vital C-based gases in the atmosphere and also crucial component of autotrophic organisms as well as chemo- and photoautotrophic microbes which are involved in the conversion of CO_2 into organic forms of C. Plant exudates and residues (dead organic matter) are incorporated into the soil from plants by heterotrophic microorganisms through transformations of organic materials. The transformation process of organic matter results in the formation of complex biochemical mixtures and microbial decomposition products from plant litter (Paul 2014). These products form complexes with soil minerals in the form of aggregates, thus ensuring the SOC persistence in the soil for decades and in some cases for centuries or millennia (Schmidt et al. 2011). A small amount of C is also transported to rivers and the ocean in the form of dissolved organic carbon (DOC) or along with erosion material from soil.

At different stages of decomposition, soil organic matter includes dead tissues of plants and animals which are less than 2 mm in size. Transformation of SOM plays a crucial role in global warming and soil ecosystem. SOM is vital not only for the stabilizing soil structure but also for the release and retention of plant nutrients and the maintenance of soil water holding capacity. Thus, it is a key factor in environmental resilience and agricultural productivity. SOM decomposition releases mineral nutrients in the soil, thus ensuring plant growth by increasing their availability (van der Wal and de Boer 2017). While improved plant vigor and higher yield ultimately ensures food security.

3 Carbon-Based GHGs

Soil serves as a double-edged sword for carbon fluxes. Soil can turn into either a net source or a net sink of GHGs due to anthropogenic activities. As a source, it involves in the emission of GHGs into the atmosphere which causes greenhouse effect as these GHGs trap thermal radiations and ultimately contribute to global warming. CO₂ and CH₄ are two leading carbon-based GHGs which are emitted from the soil due to human activities (Pachauri et al. 2014).

Nitrous oxide (N₂O) is another important form of GHGs emitted from agricultural soils and livestock, and its emission has also increased due to human activities. The inclusion of all these gases in soil carbon dioxide budgets is crucial due to the interconnection of all processes in ecosystem cycling such as C-N cycle. Global warming potential (GWP) of all these gases is different as it depends on their relative greenhouse efficiency.

CO₂ is a carbon containing gas that is normally present in the atmosphere. Before the industrial time period, the concentrations of CO₂ in the atmosphere ranged between 180 and 290 ppm by 2.1 million years (Honisch et al. 2009). Collectively considered, the atmospheric CO₂ was increased to 240 Pgc between 1750 and 2011 and was abundant at 397 ppm in 2014 (Le Quéré et al. 2016), and this was 40 times more than that before the industrial era.

Carbon dioxide discharges into the environment occur due to the oxidization of SOM or organic remnants. Soil respiration is the discharge of respired CO₂ by soil animals and also due to roots being the second largest discharge on earth (Raich and Potter 1995).

According to its GWP, CH₄ as a greenhouse gas is 28 times more vigorous (Solomon et al. 2007). It is released from the soils in a process called methanogenesis, occurring under anaerobic conditions due to the decay of organic matter. Methanogens in addition to fermenting acetate utilize carbon dioxide as an electron accepting agent instead of oxygen for their metabolism, and CH₄ is released as a by-product. So, the main origins of CH₄ discharges are waterlogged soils and most importantly peatlands, wetlands, and paddy fields (FAO and ITPS 2015). Distinctively, these greenhouse gases are substantially stored in soils (importantly carbon, a process called C sequestration). In the presence of oxygen, methanotrophic bacteria in soil flourish and use CH₄ as a carbon source – a process named

methanotrophy in which CH_4 is oxidized. So, soils in forests may be a good CH_4 sinks because their water tables are low and bacteria can grow in these (Serrano-Silva et al. 2014).

4 SOC Sequestration

The process in which carbon fixation takes place through organic matter and plant material and then stored in soil is known as SOC sequestration. It involves three stages, when we deal with CO_2 : (1) through the process of photosynthesis, CO_2 removal from the environment, (2) carbon transfer from CO_2 into biomass of plants, and (3) carbon transfer from biomass of plants into the soil as SOC stock. More rate of turnover is characteristic of this pool, enclosing freshly taken residues of plants and is easily decomposed by soil animals, normally CO_2 discharges back into the environment are caused. So, this SOC program needs much more besides accumulating atmospheric CO_2 , and it is important to look into the methods of retaining carbon in a pool of SOC. In another way, it is demonstrated by research that there is a minor power for sequestration of carbon because of its resisting property to change, and so in management, it is not responsive (Kane 2015).

A number of mechanisms are involved in the stabilization of newly incorporated carbon in the soil (Six et al. 2006; Kane 2015). In a chemical process, carbon is strongly adsorbed by clay through chemical bonds preventing carbon consumption by other organisms. In a biochemical way, resynthesis of carbon is possible into more complex structural molecules, and decomposition may be prevented. Carbon stabilization efficiency is shaped by the three main procedures that rely on a multitude of biotic and abiotic factors (Six et al. 2006; Kane 2015).

4.1 SOC and Biodiversity

The various living organisms found collectively in soil is termed as soil biodiversity. The organisms that make up soil diversity interact with other plants and animals as well as one another and ultimately form a web of intense biological activity that can be detected as well as studied (Orgiazzi et al. 2016). Soil biodiversity not only greatly contributes to the creation of SOM using the organic litter of the soil, but it also contributes to the augmentation of SOC content in the soil to some extent. Additionally, the quality as well as the amount of SOM and SOC indirectly determines the density along with the activity of plant roots and their interaction with soil biota. In this manner, the structure of the microbial community in the soil is greatly influenced both by the quantity and the quality of SOC as well as the diversity of plant present in the soil (Thiele-Bruhn et al. 2012).

4.2 Importance of Soil Biodiversity

In 1992, during the Convention of Biological Diversity at the United Nations (UNCBD), the vitality of biodiversity was made official. It stated that biodiversity has a key role to play by ensuring that the ecosystem continues to function at an optimal level and every single organism found in the ecosystem, has its place in the ecosystem regardless of its mass and density. The World Soil Charter, released in 2015, referred to soil as the key to global diversity, which includes both flora and fauna present in the ecosystem. This biodiversity plays an essential part in sustaining the various functions of the soil and indirectly supports the properties and the services of the soil. Thus, the maintenance of soil biodiversity is critical to its various purposes (FAO 2015).

The soil biodiversity, i.e., the organisms found in the soil like the protozoa, fungi, bacteria, worms, and insects along with the various invertebrates and mammals, merge with the SOC and form the metabolic capacity of the soil. This capacity is believed to play an important role in the production of food and increasing the resilience of soil in response to climate change. The complex communities of soil organism are responsible for (i) the determination of the size and the course of C fluxes occurring between the soil and the atmosphere, (ii) cycle the SOC that deeply impact the nutrient availability, i.e., the acquisition of nutrients in plants is helpful especially when it works in tandem with associations formed by soil microorganisms, (iii) with the help of aggregation, the physical structure of the soil is somewhat improved, and (iv) boost crop pollination along with biological pest control (FAO and ITPS 2015).

4.3 Soil Biodiversity Losses

Various functions of the ecosystem are seen to have an impact on the density of losses faced by the biodiversity of soil. This mainly includes nutrient retention in soil, SOC decomposition, and cycling of nutrients (FAO and ITPS 2015). Inadequate land management methods and environmental modifications affect various soil communities and rapid decline in the biodiversity of soil (Fig. 1) (Wall et al. 2012). The fragile web of various interactions existing between the communities is damaged by poor agricultural practices that disrupt the agronomic ecosystems. The interactions existing between pests and their natural enemies ultimately have a negative impact on SOC stocks within the soil. Since physical properties of the soil are unable to explain the ratio of loss faced by SOC, it can be assumed that the SOC stability relies on the diversity as well as the activity of the soil organisms (Gardi and Jeffery 2009).

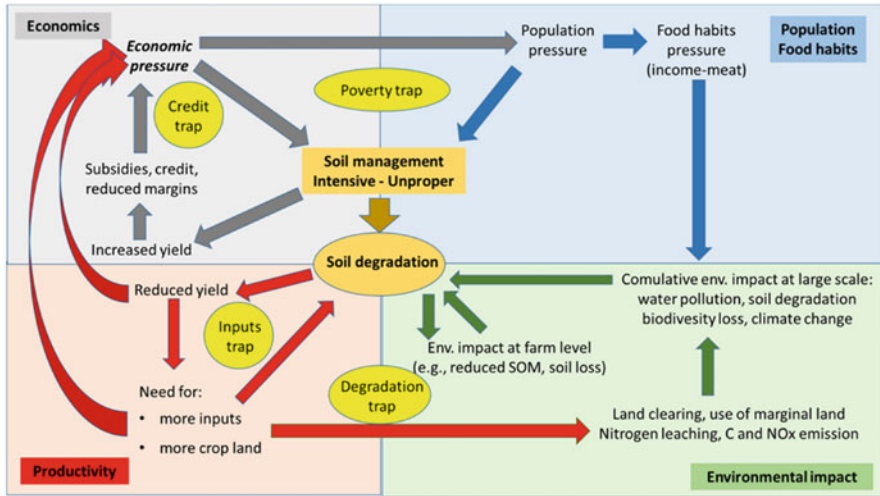


Fig. 1 Impact of land use decisions on soil biodiversity (Cited from Gomiero 2016)

5 SOC Status Under Changing Climate

According to current studies, the range of soil carbon responses varies from small losses to modest gains. On the basis of soil types and region, it is difficult to predict the multiple effects of climatic change on the soil as it gives the complex interaction between increased decomposition and productivity besides moisture and temperature (FAO and ITPS 2015; Keesstra et al. 2016).

The major factors that control the SOC dynamics include precipitation and temperature (Deb et al. 2015). The microbial decomposition of SOC increases with the increase in the temperature (Keesstra et al. 2016). Indeed, there is a strong support for the idea that increasing temperature accelerates the climatic change (Crowther et al. 2016). The ecosystem dynamic is greatly affected by the climatic change than the combined effect of temperature and carbon dioxide (Pachauri et al. 2014).

The increase in net primary productivity is due to increased anthropogenic activity in atmospheric carbon dioxide. This increased NPP (net primary productivity) has a negative feedback on atmospheric CO₂ due to increased SOC input (van Groenigen et al. 2014; Amundson et al. 2015). According to progressive nutrient limitation theory, the response of NPP is limited by the soil nutrient supply specifically of nitrogen. However, it is not clear that either increased NPP will translate into increased SOC storage.

The consequences of the human actions on the global climate are still not obvious, which partly owes to the limited knowledge and understanding about soil respiration and its depiction in various Earth systems (Gougoulias et al. 2014). For instance, on SOM decomposition, a high uncertainty relates to so-called priming

effect, which is indeed a vital process in ecosystem carbon balance (van der Wal and de Boer 2017). The priming effect actually increased the decomposition of SOC stocks in the result of the addition of easily degradable compounds. Due to this priming effect, the prediction of the future soil C responses to a changing climate becomes more uncertain (FAO and ITPS 2015).

6 Nitrogen Fixation and Reactive Nitrogen

The nitrogen cycle is crucial to earth's biochemistry at the global level, in which, enormous natural nitrogen moves from the air into marine and terrestrial ecosystems through the process of biological nitrogen fixation (BNF), resulting in the conversion of unreactive molecular nitrogen into reactive ammonium compounds. After fixation, nitrogen is subsequently transformed to oxidized compounds and amino acids by microorganisms and then finally returned as molecular nitrogen to atmosphere from marine and fresh waters, soils, and sediments through the process of microbial denitrification (Galloway et al. 2004). Initial steps of BNF result in compounds that contain N_r (reactive nitrogen) including PAN, NH_4 , NO_2 , NH_3 , N_2O , NO , and HONO as well as other organic nitrogen compounds which are widely distributed in the atmosphere, specifically in cryosphere and play a vital role in marine and terrestrial ecosystems. Galloway et al. (2003) discussed that N_r being component of this earth element basically serves the role of tracer for the biogeochemical cascade. Oxidized form of nitrogen (NO_x) performs a primary role in the production of radical species photochemical ozone and other oxidants (Wayne 1991), and it is also vital for increasing oxidizing capacity of the atmosphere (Isaksen et al. 2009). Emission of N_2O , as a result of denitrification process, also plays an important role in radiation balance on earth and ozone layer chemistry specifically of stratosphere by lysis of N_2O in the presence of light (Wayne 1991). Mere sources of N_r production are BNF and NO_x photolysis in the absence of anthropogenic activities.

6.1 Natural Sources of Fixed Nitrogen

The main natural sources of new N_r in the environment are biological nitrogen fixation and lightning. Fowler et al. (2013) estimated that among global natural sources of N_r ($203 \text{ Tg N year}^{-1}$), lightning just comprised approximately 2.4%. Actually, biological nitrogen fixation in terrestrial ecosystems has been largely influenced by human activities after industrialization. Looking at the pre-industrial BNF estimates, terrestrial ecosystems constituted approximated 1/3 of total BNF as compared to 2/3 of marine ecosystems (Fowler et al. 2013).

6.1.1 Biological Nitrogen Fixation

In purview of global nitrogen cycle, biological nitrogen fixation is the most important source of N_r , whether it is in terrestrial or marine ecosystem. Biological nitrogen fixation offers imperative reference while enumerating the value of human inputs in conformity with the nitrogen cycle at the global level because this is the important natural input regarding reactive nitrogen (Vitousek et al. 2002). The magnitude from lightning, discussed later, as this magnitude is smaller than other estimates of BNF, although significant for ozone formation and maintenance regarding the oxidation potential of the atmosphere at the global level.

The procedure of biological nitrogen fixation was first recognized in last decades of the nineteenth century and since then considered as a focal point of ecological interest. There are many limits in understanding why microorganisms are not able to fix all available N as it can benefit them compared to competitor non-nitrogen-fixing organisms, although there is vast capacity in ecosystems to fix available atmospheric N_2 . In various ecosystems, the frequently available N_r in the soil generally downregulates BNF, so perhaps N_r application on cultivated soil and deposition into the seminatural region has lowered nonagricultural BNF (Galloway et al. 2004). The present knowledge about strategies has not yet delivered clear solutions according to these queries. The analysis on this subject by Vitousek et al. (2013) presents an estimation on annual pre-industrial BNF into terrestrial ecosystems of 58 Tg N, with an extent from 40 to 100 Tg, with a discussion on modern perception and restrictions. The doubtful range is wide as it represents the difficulty in estimation of the constituent terms. The range inferred by Vitousek et al. (2013) is lesser than mostly available approximations, mostly previous values proposing prior to industrial BNF in range of 100–290 Tg N year⁻¹. Nevertheless, this recent estimate is based on calculations of hydrological nitrogen losses in terrestrial ecosystems, and nitrogen portion that is denitrified in rivers or oceans might also be overemphasized.

N cascade in the waters along with BNF and denitrification process is reviewed by Voss et al. (2013). Estimates regarding each term propose also surplus of denitrification process than BNF or equilibrium of both processes (Gruber and Galloway 2008). Nevertheless, doubts among the specific terms prevent a vibrant consent. The sustaining mechanism that maintains the balance between BNF and denitrification at global scale has yet not been verified. However, iron and phosphorus (P) availability may be one of the contributors. By covering approximately three quarters on the Earth's surface and oceans simply take over surface while relatively small fluxes per unit area hold the potential of substantial contribution to overall N fluxes of the atmospheric molecular nitrogen reservoir and marine reactive nitrogen forms. One of major uncertainties in the rates regarding marine BNF is spatial variability, as these are associated with the supply of other essential nutrients too like Fe and P are essential for many biological processes because their supply is also spatially variable (Berman-Frank et al. 2007). Large BNF rates have basically recommended for the Atlantic oceans than the Pacific because of more nutrient availability (Voss et al. 2013).

6.1.2 Lightening

In addition to BNF, nitrogen is also fixed as NO_x by the natural process of lightning, which presents N_r to rather far off areas of the troposphere. The process has been scrutinized via direct measurements and also spacecraft remote sensing of lightning activity has supported this process. Accessible data and models are used in the estimation of global production, but with considerable unreliability to some extent due to strain in up-scaling, by Brasseur et al. (2006), who also examined viable effects of changing climate on NO_x production rate via lightning. These authors enumerate increasing NO_x production rate with an increase of global temperature ranging 3–12% per 8 K. Overall, worldwide informant strength estimates vary from 2 to 10 Tg N year⁻¹ (Tie et al. 2002; Cape et al. 2004), with contemporary values or at 5 Tg nitrogen annually. For this evaluation 5 Tg nitrogen per year, value is assumed.

6.2 *Impact of Anthropogenic Activities on N Fixation*

Nitrogen fixation of compounds based on anthropogenic activities is dubious but well known than natural process of fixation. Because, more substantial measurements have been made to original sections and these are also subjected to considerable scientific study, with continuous supervision of some considerable industrial origins. The gases produced from the transport and industry are oxidized compounds of N, e.g., nitrogen oxide (NO) and nitrogen dioxide (NO_2), burning of biomass, and reduction of nitrogen (N) as ammonia (NH_3) via Haber-Bosch process.

Biological N exists widely in the world as amines in considerable amount (Cape et al. 2004; Jickells et al. 2013). Nevertheless, there is no evidence that these are reactive nitrogen representing compounds, which is acquired from the BNF or commercial sources of ammonia or nitrogen oxides. The involved compounds and mechanisms in the discharge of biological nitrogen and their streaming into the environment are not well known to allow the upscaling for territorial or worldwide estimation of their original strength. Consequently, a substantial involvement to the manmade discharge of N_r may be lacking from the worldwide reactive N budgets raised to date, comprising the one depicted here, as these compounds are dubious to depict more key origins of N_r .

Anthropogenic fixing of reduced nitrogen, i.e., ammonia, is via nitrogen fixing plants and mainly through the process of Haber-Bosch where hydrogen and nitrogen react together in the presence of catalyst and extreme temperature and pressure (Erisman et al. 2008). During the early years of the twentieth century, the process was evolved and supplying 120 Tg nitrogen as ammonia per year, of which 80% is used as fertilizer in agriculture and 20% as raw material for commercial purposes (Galloway et al. 2008). The outcome of N usage in the production of crops differs, with only 17% utilized in crops, milk, and meat productions by humans, the rest of

this is lost into the soils, freshwater bodies, and the atmosphere (Leach et al. 2012; Noor 2017). In decades to centuries, the process of denitrification returns most of the Nr to atmosphere as dinitrogen, but the lifetime in dissimilar repositories come back to the atmosphere allows slots for movement in reactive form in freshwater bodies or the atmosphere. Some of the Nr applied in the form of fertilizer is discharged to the atmosphere as ammonia relying on the comparative balance between ambient volumes of ammonia and the equilibrium volumes with the concentration of ammonium within intercellular fluids (Sutton et al. 1995). The total per year production of 120 Tg nitrogen as ammonia via the process of Haber-Bosch depicts the major single involvement to Nr formation via human activities. The total contribution by nitrogen fixing crops to agricultural crops is approximately 60 Tg per annum (Herridge et al. 2008), while the total production of Nr due to anthropogenic activities is 180 (+20) Tg N per annum.

6.3 Nitrogen Fixation in Cropland

N-fixing crops present considerable volumes of Nr to soils. In the evaluation of crop BNF, Herridge et al. (2008) assembled data from the uninterrupted computation of BNF from an array of agroecosystems worldwide and upscaled N fixation rates per year via land use and clipped data to compute a worldwide total. The present worldwide BNF from crops and ruminating savannahs computed by Herridge et al. (2008) is 50–70 Tg N per year. For the sake of condensing data, a principal value of 60 Tg nitrogen per year as the worldwide per year Nr streaming for BNF in cropland is included in this evaluation. The BNF value for cropland is near to the pre-commercial BNF and is identical within the recent array of unreliability.

7 Overview of Nitrogen Cycle

The chemical process of naturally fixed reactive nitrogen takes place in the atmosphere, earth, and oceanic environments. As a result of chemical processing, a large variety of inorganic and organic products are formed. The quantities of Nr cycling in each of these environments and their magnitudes show that worldwide component processes 240 Tg nitrogen in different forms, while 230 Tg nitrogen per year processing takes place in marine, and probably 100 Tg nitrogen per year processing takes place in the atmosphere, neglecting the discharges into and out of the huge environmental nitrogen source. Studies showed that the environmental occupancy time is small as compared to oceanic and earth environments, and with the exception of earth environments, the normal lifespan of Nr is a few decades (Galloway et al. 2013). Such an average over worldwide biosphere is confusing as long-lived sources are there such as peat lands contain organic matter and ice sheets, deserts, and aquifers contain reactive nitrogen. In oceanic and earth environments, the processing

of the N_r generation takes place by microbial activity and metabolic activities of plants and their conversion into plant and proteins of microbes. The N_r in agriculture can have direct use as food for human or for feeding purpose for livestock and its conversion, fairly in an ineffectual way to protein and used by humans as food. The conversions resulting from initially fixed nitrogen are important for discharges into groundwater or the environment.

The transfer of reactive form of nitrogen (N_r) from soils to fresh water and atmosphere has a broader application in understanding the leakages of a different form of N_r in soils, water, and vegetation. Galloway et al. (2003) defined the concept of the N cascade to demonstrate many N_r interconversions as well as leakages of N_r during processes of original fixation and denitrification ultimately return back to the atmosphere as N_2 . It is helpful to consider an example which describes the fate of nascent NH_3 molecule production to explain the point: consider nitrogen (N) atom converted into NH_3 molecule during the Haber-Bosch process. As it is applied as N fertilizer to the soil, while transformed in many forms before returning as N_2 into the atmosphere.

8 Conclusion

The global N cycle has been greatly modified by human activity, and it is the most perturbed biogeochemical cycle on the planet on which ecosystems depend. Many components of the global budget have been quantified over the last 20 years. However, many fluxes are subjected to large uncertainties and require extensive measurements to constrain the current range of values. Approximately half of the global human population is dependent on the increased yields of agricultural crops owing to fertilizer N usage. These interventions have substantially enhanced the carbon sequestration resulting from N_r deposition to forests and other seminatural terrestrial ecosystems. The full scope of the global carbon cycle and its interdependency on SOC dynamics and relation to other biogeochemical cycles is yet to be fully understood. More accurate SOC measurement, mapping, monitoring, and reporting can contribute to achieving progress in this regard. Land management practices and systems that foster SOC sequestration should aim to retain carbon in the soil over the long term.

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