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Impact of Microorganisms on Climate Change: A Review

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ABSTRACT

Biosphere Reserves all over the world are areas that are deliberately and purposely kept to promote green economy and most importantly mitigate the effect of Global warming and climate change. The problems of climate change arise from the higher concentration of greenhouse gases in the atmosphere which exert a warming effect on the earth. Control of anthropogenic sources and greenhouse gases are constantly discussed and extensively researched in this matter, while the significance of microorganisms remained neglected. Although microorganisms have a contributory effect in global warming as in the case of methanogenes in the rumen of ruminants which have been implicated to increase the environmental methane gases during digestion, the role they play in converting greenhouse gas to a useable form in the soil and water hence, reducing global warming cannot be over emphasized. The current review aimed to stress the neglected global importance of microorganisms in climate change. Overall, this review further support the key role biosphere reserves play in protecting soil and plant microorganisms in response to climate change control.

***Keywords*:** Climate Change, Microorganism, Biosphere reserves, Carbon cycle, Nitrogen fixation

1. INTRODUCTION

Anthropogenic human activities, a major cause of climate and environmental change, cause unprecedented animal and plant extinctions and loss of biodiversity (Barnosky *et al.*, 2017., Crist and Mora, 2017., Johnson *et al.*, 2017., Pecl *et al.*, 2017). The Loss of species, habitats and communities are well researched and documented (UN, 2018).

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But microorganisms are generally not discussed in the context of climate change (Dupre´ 2008; Walsh 2015). The global climate is predicted to change drastically over the next century and various parameters will be affected in this changing environment (Houghton *et al.*, 2001). This is because atmospheric CO_2 concentrations increase continuously (IPCC Climate Change, 2007). Climate change is happening because there has been an increase in temperature across the world.

Recent research on biological responses to climate exchange has focused on animals and plants and their interactions (Pounds *et al.*, 2006). It has been shown by several studies that certain groups of microorganisms preserved in lake sediments such as phototrophs and aerobes, may be useful in reconstructing recent environmental changes (Coolen *et al*., 2004a, 2004b). Microorganisms play important roles in carbon and nutrient cycle, animal, human and plant health, agriculture and the global food web. The microorganisms are involved in the emission and removal of greenhouse gases like carbon dioxide and methane, which in turn are responsible for climate change (Microbiology Online 2015). Microbes play an important role as either generators or users of these gases in the environment as they are able to recycle and transform the essential elements such as carbon and nitrogen that make up cells (Joshi and Shekhanat, 2010). If we ignore the importance of microbial processes, we fundamentally limit our understanding of Earth's biosphere and response to climate change and hence jeopardize efforts to create an environmentally sustainable future (UN, 2018). The microorganisms are important to carbon and other biogeochemical cycles, and their role with respect to climate change requires attention (Walsh 2015).

This review aims to call the attention of policy makers and the international community to the importance of microorganisms in fighting climate change while elucidating the role of biosphere reserves in mitigating climate change.

2. CLIMATE CHANGE – A WORLD PROBLEM

Climate is defined as average weather conditions of a certain region, including temperature, rainfall and wind. Climate change is the most complex global issue of the present time, it includes scientific, economic, social, political, moral, and ethical aspects (NASA 2015a). The Earth is surrounded by a thick layer of gases which keeps the planet warm and allows plants, animals and microbes to live. These gases work like a blanket. Without this blanket the Earth would be 20–30 °C colder and much less suitable for life. It occurs as a result of higher atmospheric concentrations of four greenhouse gases – carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons (US EPA 2016). Green House effect is the phenomenon whereby the earth's atmosphere traps solar radiation, and is mediated by the presence in the atmosphere of gases such as carbon dioxide, water vapor, and methane that allow incoming sunlight to pass through, but absorb the heat radiated back from the earth's surface.

The severity of the problem is evident from the fact that the daily level of carbon dioxide in the atmosphere surpassed 400 ppm for the first time in human history in 2013. Such high levels used to occur, approximately three to five million years ago during the Pliocene era (NASA 2015a). Carbon dioxide as one of the causes of climate change comes from fossil fuel use in different sectors like transportation, building, heating, cooling and the manufacture of cement and other goods. It is also released from natural processes, such as the decay of plant matter, respiration and microbial decomposition of organic matter (Davidson and Janssen, 2006).

Methane is a very powerful greenhouse gas because it traps about 20 times as much heat as the same volume of carbon dioxide. As a result it warms the planet up to 20 times more than carbon dioxide. In the carbon cycle methanogens convert carbon dioxide to methane in a process called methanogenesis. Nitrous oxide is produced during fertilizer use and fossil fuel burning (Sanford *et al*., 2012). Chlorofluorocarbons (CFC-11 and CFC-12) which were used extensively as refrigerant and in other industrial processes before their presence in the atmosphere were found to cause stratospheric ozone depletion is another agent of climate change. Now a day, the abundance of chlorofluorocarbon gases is decreasing as a result of international regulations designed to protect the ozone layer.

Ozone is a greenhouse gas that is continually produced and destroyed in the atmosphere by chemical reactions. In the troposphere, human activities have increased ozone through the release of gases such as carbon monoxide, hydrocarbons and nitrogen oxide, which chemically react to produce ozone. As mentioned above, halocarbons released by human activities destroy ozone in the stratosphere and have caused the ozone hole over Antarctica.

Water vapour is the most abundant and important greenhouse gas in the atmosphere. However, human activities have only a small direct influence on the amount of atmospheric water vapour. Indirectly, humans have the potential to affect water vapour substantially by changing climate. For example, a warmer atmosphere contains more water vapour. Human activities also influence water vapour through CH_4 emissions, because CH_4 undergoes chemical destruction in the stratosphere, producing a small amount of water vapor.

Aerosols are small particles present in the atmosphere with widely vary in size, concentration and chemical composition. Fossil fuel and biomass burning have increased aerosols containing sulphur compounds, organic compounds and black carbon (soot). Human activities, such as surface mining and industrial processes, have increased dust in the atmosphere. Natural aerosols include mineral dust released from the surface, sea salt aerosols, biogenic emissions from the land and oceans, sulfate and dust aerosols produced by volcanic eruptions (Charu *et al*., 2014; Hasin *et al*., 2010; Olufemi, 2014).

3. MICROORGANISMS AS A TOOL IN SOLVING CLIMATE CHANGE CHALLENGES

Microbial processes play a central role in the production and utilization of the key biogenic greenhouse gases (carbon dioxide, methane and nitrous oxide) and are likely to respond rapidly to climate change. It is widely accepted that microorganisms played a major role in determining the atmospheric concentrations of greenhouse gases (Singh *et al.,* 2010; Zimmer, 2010). Microbial organic matter decomposition is highly sensitive to climatic trends (Crowther *et al*., 2015). Microbes are, in fact, responsible for about 85% of world methane release (Zimmerman and Labonte, 2015). When microbial communities and biogeochemical cycles are linked together they act as a good mechanism to solve climate change. This can be exemplified by the enzyme methyl coenzyme M reductase, which is responsible for the transformation of carbon dioxide into methane. Warming trends could drive many such local microbes to release larger amounts of methane (Svoboda, 2015a). Methane-consuming microorganisms are capable of removing atmospheric methane even at very low concentrations and occur in both land and sea (Zimmerman and Labonte, 2015). In this way, microbes contribute toward controlling methane emission which in turn regulates climate change. It is important to note that microorganisms use greenhouse gases as energy source to build their cell (Singh *et al*., 2010).

4. MICROORGANISMS AND CARBON CYCLE

The global carbon cycle is mainly depending on microbial communities that fix atmospheric carbon, promote plant growth, and degrade or transform organic material in the environment. Since the Earth is a closed system with a finite supply of essential elements such as hydrogen (H), oxygen (O), carbon (C), nitrogen (N), sulfur (S) and phosphorus (P), recycling of these elements is fundamental to avoid exhaustion. Microbes are critical in the process of breaking down and transforming dead organic material into forms that can be reused by other organisms. This is why the microbial enzyme systems involved are viewed as key 'engines' that drive the Earth's biogeochemical cycles.1 microorganisms play key role in determining the longevity and stability of this carbon and whether or not it is released into the atmosphere as greenhouse gas which means mediate the processes of carbon cycle (Weiman, 2015).

Carbon is transferred from the atmosphere to soil via 'carbon-fixing' autotrophic organisms, mainly photosynthesizing plants and also photo and chemoautotrophic microbes that synthesize atmospheric carbon dioxide (CO2) into organic material (Johnson *et al*., 2017; Pecl *et al*., 2017) (**Fig. 1**).

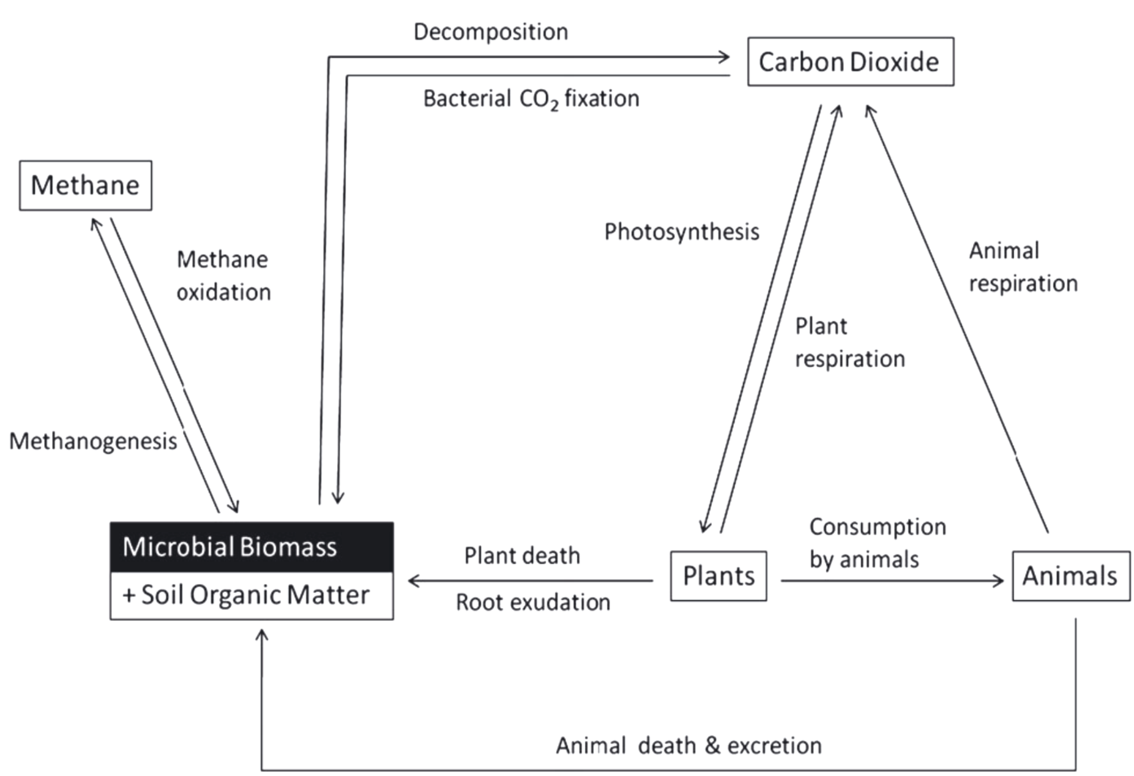

Figure 1. The terrestrial carbon cycle with the major processes mediated by soil microorganisms

Microorganisms are critical in the process of breaking down and transforming dead organic material into forms that can be reused by other organisms. This is why the microbial enzyme systems involved are viewed as key ‘engines’ that drive the Earth’s biogeochemical cycles. Carbon is transferred from the atmosphere to soil via ‘carbon-fixing’ autotrophic organisms such as photosynthesizing plants, photo and chemoautotrophic microorganisms these are synthesis atmospheric carbon dioxide in to organic material. Infact, microorganisms use carbon as a metabolism substrate due to the highly consumed atmospheric carbon dioxide. From this elucidation, microorganisms help extract carbon from non-living sources and make the carbon available to living organisms (including themselves). Soil microorganisms regulate the amount of organic carbon stored in soil and released back to the atmosphere, and indirectly influence carbon storage in plants and soils through provision of macronutrients that regulate productivity (nitrogen and phosphorus) (Singh *et al*., 2010; Bardgett and Van der Putten, 2014). Plants remove CO_2 from the atmosphere through photosynthesis and create organic matter that fuels terrestrial ecosystems. Conversely, autotrophic respiration by plants (60 Pg C per year) and heterotrophic respiration by microorganisms (60 Pg C per year) release CO_2 back into the atmosphere (Singh *et al*., 2010). Temperature influences the balance between these opposing processes and thus the capacity of the terrestrial biosphere to capture and store anthropogenic carbon emissions (currently, storing approximately one quarter of emissions) (Fig.1).

Table 1. CO_2 Emission by Countries

Rank	Country	Annual emissions in 2017	Percentage
1	China	9,839	27.2
2	USA	5,269	14.6
3	India	2,467	6.8
4	Russia	1,693	4.7
5	Japan	1,205	3.3
6	Germany	799	2.2
7	Iran	672	1.9
8	Saudi Arabia	635	1.8
9	South Korea	616	1.7
10	Canada	573	1.6

Source: World economic forum (2019)

The above **Table 1** shows the annual emission in PPM by major countries and their percentage. According to the 2017 estimate, China and USA lead countries of the world in terms of environmental pollution and the production of Carbon dioxide.

The two countries are responsible for more than 40% of the worlds CO_2 Emissions. The implications of this are that these areas/region are heavily prone to the effects of environmental pollution due to their pace of socio-economic activities. It has been observed that areas of high power generator machines for industrial and automobiles purposes are prone to the effects of environmental challenges and climate change than other areas, for examples, in Great Britain, Pittsburgh (USA), Ruhr (Germany), China and Japan (Asia), etc. are associated with high level environmental challenges. The most recent fire outbreak in Australia and the great storm in Philippines were attributed as natural phenomena and evolution of the ecosystem (Okpara, 2011).

5. MICROBIAL METHANE CYCLE

Methane plays a critical role in the global carbon cycle because it is at the bottom of the redox scale (**Fig. 2**). Methane is a potent greenhouse gas with a warming potential 34 times stronger than that of carbon dioxide over a time period of 100 years (Myhre *et al.*, 2013). Cycling of carbon between carbon dioxide and organic compounds are considered as ecologically significant.

The carbon atom found in the methane molecule is fully reduced; it cannot accept further electrons, but is a potential electron donor. At the other extreme of the redox scale lies carbon dioxide, the most oxidized form of carbon found in the cycle. Carbon dioxide cannot donate electrons but is a potential electron acceptor.

Under highly reducing conditions in the absence of other potential electron acceptors such as nitrate, sulfate, or ferric iron, these substrates can be converted to methane. Some methane-producing bacteria are able to produce methane by coupling the reduction of carbon dioxide to hydrogen oxidation, others by further reducing the small organic substrates fermentatively. Methane (CH_4), a greenhouse gas, most of the time enters to atmosphere because of microbial action. Methane consuming microorganisms are critical to maintaining a healthy climate on Earth. Bacteria use methane for metabolism as energy source (Semrau *et al.*, 2010; Bosquet *et al.*, 2006). Methanotrophic bacteria's consume methane as their only source of energy and convert it to carbon dioxide during their digestive process.

These bacteria can consume huge concentration of methane which is helpful in reducing methane emission from methane producing factories and landfill (Charu *et al.*, 2014; Shindell *et al.*, 2012). In the presence of oxygen, CH_4 is oxidized to CO_2 by Methanotrophic bacteria. The oxidation of CH_4 to CO_2 completes the carbon cycle. Microorganisms use high amount CH_4 compounds which are found everywhere (Zimmerman and Labonte, 2015). In anaerobic conditions just like deep compacted mud, carbon dioxide easily changed in to methane this is accomplished by methanogenic bacteria.

The conversion process needs hydrogen, yields water and energy for the methanogens. To accomplish the recycling pattern another group of methane bacteria called methane oxidizing bacteria or methanotrophs (literally "methane eaters") can convert methane to carbon dioxide.

This conversion, which is an aerobic process, also yields water and energy. In the presence of oxygen, CH_4 is oxidized to CO_2 by Methanotrophic bacteria. The oxidation of CH_4 to CO_2 completes the carbon cycle.

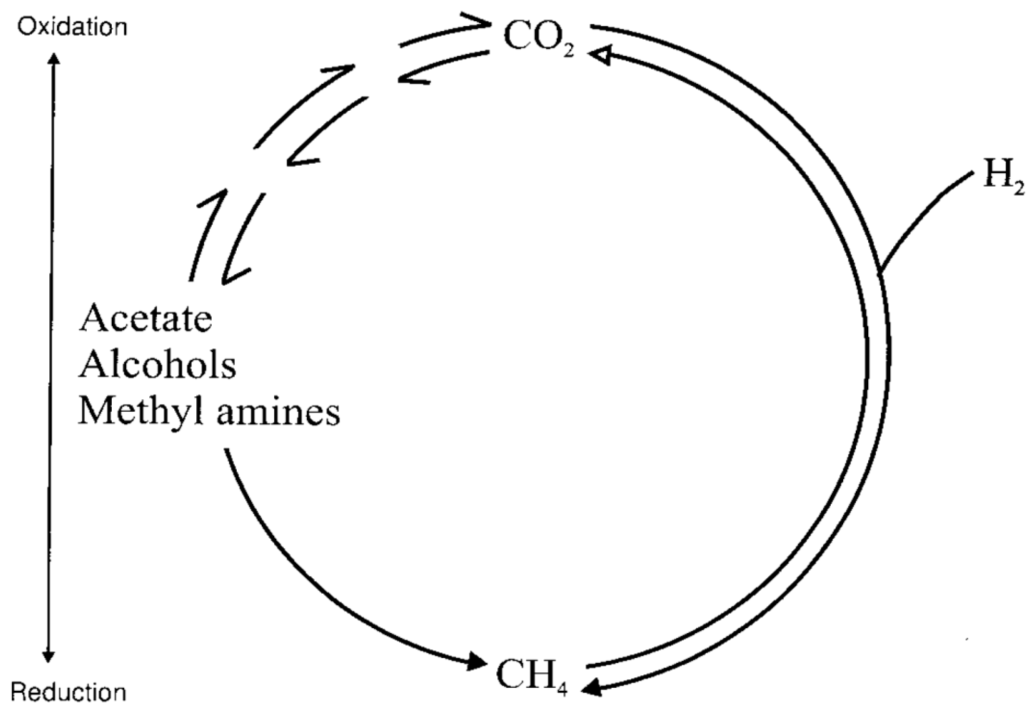

Fig. 2. A simple depiction of the carbon cycle in soils. Methane is the most reduced form of carbon in the cycle, carbon dioxide the most oxidized

6. MICROORGANISM AND NITROGEN CYCLE

Nitrogen exists in an elemental form. It is the major component of the air constituting about 78% of the gases in the earth atmosphere. There are also different nitrogen gaseous compounds that exist in the atmosphere including NH_3, NO and N_2O. Nitrogen is in the form of a very stable molecule (N_2) which is unusable by plants and animals without fixation. Nitrogen fixation is the process of changing atmospheric nitrogen into chemical forms which is usable by living things. N_2 enters in to biosphere via biological fixation. Biological nitrogen fixation will ever totally replace industrial fixation for intensive agriculture. *Rhizobium* bacteria which cause formation of nodules on the roots of legumes such as soybeans and alfalfa. The bacteria are fairly specific for certain plants for example; the species which infects soybeans will not infect alfalfa.

The bacterium attaches to a root hair of the plant and in response the plant forms a hollow thread leading into the root. Bacteria grow through this infection thread and eventually initiate formation of a nodule on the root. As much as 30 percent of the weight of a nodule may be bacteria. The plant supplies energy from the air in a form the plant can use through fixation. This is an example of symbiotic nitrogen fixation (Anne, 2010; Vitousek *et al.*, 2013). Specific bacteria (*Rhizobium trifolium*) possess nitrogenous enzymes that can fix atmospheric nitrogen into a form (ammonium ion) that is chemically useful to higher organisms As part of the symbiotic relationship, the plant convert the 'fixed' ammonium ion to nitrogen oxides and amino acids to form proteins and other molecules like alkaloids (Jama *et al*., 2013) (Figure 2). Nitrogen cycle mainly the conversion of nitrogen from one state to another state. Most of the time microorganism pushes the system in order to harvest energy or to accumulate nitrogen in a form needed for their growth and development.

The major transformations of nitrogen are involved through the following steps.

6. 1. Nitrogen fixation

The first step in the process of making/transforming nitrogen usable/taken up by plants. Microbes responsible for convert nitrogen into ammonium. Two kinds of nitrogen fixing bacteria are recognized. The first kind, the free-living (non symbiotic) bacteria, includes cyanobacteria or blue-green algae, *Anabaena*, *Nostoc*, *Azotobacter*, *Beijerinckia*, and *Clostridium*. The second kind comprises the mutualistic (symbiotic) bacteria mainly *Rhizobium* associated with leguminous plants. Nitrogen fixation is carried out by free living and symbiotic microorganisms in a good manner. These bacteria have the nitrogenase enzyme that combines gaseous nitrogen with hydrogen to produce ammonia, which is converted by the bacteria into other organic compounds (Anne, 2010; Orr *et al*., 2011).

6. 2. Nitrification

The process ammonium transformed into nitrates by living things. Nitrates are what the organisms can absorb. The transformation of ammonia to nitrate is completed by soil living bacteria and other nitrifying bacteria. In the primary stage of nitrification, the oxidation of ammonium (NH_4^+) is done by bacteria such as the *Nitrosomonas* species, which converts ammonia to nitrites (NO_2^-). Other bacterial species such as *Nitrobacter*, are responsible for the oxidation of the nitrites into nitrates (NO_3^-). Ammonia is converted to nitrates or nitrites because ammonia gas is toxic to plants. Ammonium ion useful in energy source microorganisms involved in side the system. Nitrite is toxic to plant and animal. It must be immediately convert in to nitrate by different species (Ward, 2011, Wunderlin *et al*., 2012).

Assimilation: This step indicates that the mechanism of plants gets nitrogen. Plants can uptake nitrates from soil by their root hairs. Eventually, it is used in cellular component production like amino acids, nucleic acids, and chlorophyll. In plants that have a symbiotic relationship with rhizobia, some nitrogen is assimilated in the form of ammonium ions directly from the nodules. Other life form also seeking nitrogen through food chain structure (Ram and Shwetang, 2014).

6. 3. Ammonification

Is the stage of decaying? During living things are died, decomposers like fungi and bacteria turn nitrogen to ammonium. Later it can reenter in the normal nitrogen cycle. In the N_2 process the nitrogen is released usually in the form of ammonia. The process is termed as ammonification or mineralization. Many types of enzymes are involved for example Gln Synthesis (Cytosolic and Plastid), Glu 2-oxoglutarate aminotransferase (Ferredoxin and NADH dependent) and Glu Dehydrogenase. Actually in soil this takes the form of the ammonium ion (NH_4^+) which has a positive charge. This charge tends to bind the nitrogen to clay minerals of the soil, an advantage in that the nitrogen is not readily lost by leaching or runoff. It has the disadvantage that it cannot easily migrate to reach plant roots for uptake (Anne, 2010; Ram and Shwetang, 2014).

6. 4. Denitrification

At the end of cycle extra nitrogen molecules in the soil move out to atmosphere. Denitrification is the reduction of nitrates back into the largely inert nitrogen gas (N_2) for completing cycle (**Figure 3**). This kind of task is performed by special and unique group of bacteria like Pseudomonas and Clostridium. They use nitrate as an electron acceptor in the place of oxygen during respiration. The denitrifying bacteria use nitrates in the soil to carry out respiration and consequently produce nitrogen gas, which is inert and unavailable to plants. The process is takes place in the absence of oxygen commonly in waterlogged soils. Eventually, nitrate is converted to nitrogen gas and reenters to atmosphere (Anne, 2010; Groffman, 2012).

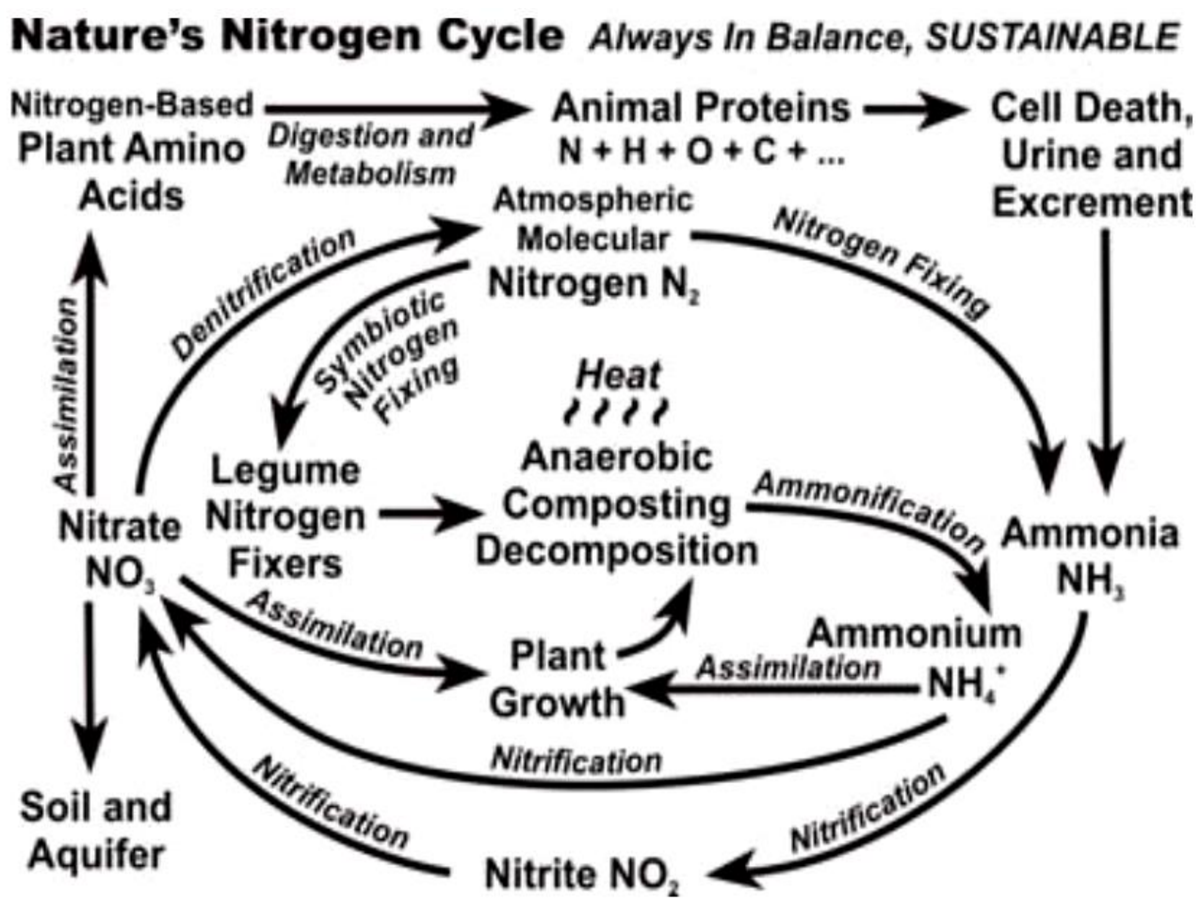

Fig. 3. Nitrogen Cycle

7. CONCLUSIONS

Microorganisms through nutrient cycling play a dual role in GHG production and utilization. They utilize GHG for their energy requirements which reduce global warming and climate change. Microorganisms make a major contribution to carbon sequestration. Microorganisms also contribute substantially to greenhouse gas emissions via heterotrophic respiration (CO_2), methanogenesis (CH_4) and denitrification (N_2O). The role that microorganisms play in determining the atmospheric concentration of greenhouse gases cannot be overlooked, however the scientific world still needs to conduct more studies in this regards.

If adequately utilized, microorganisms could be an important natural resource for controlling climate change. However, if proper study is not conducted, it could act as a mechanism that accelerates the impacts of global warming.

Recommendations

Less chemical consumption should be used on farms during crop spraying instead of biopesticides derived from forest plant extracts that are environmentally friendly should be encouraged. The use of synthetic chemical fertilizer in agriculture should be minimized. Afforestation program should be encouraged all over the world. Further scientific investigation on how microorganisms use and produce GHGs in response to climate change should be conducted.

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