Environment Pollution and Climate Change
ISSN: 2573-458X

Endeshaw et al., Environ Pollut Climate Change 2018, 2:1
DOI: 10.4172/2573-458X.1000147

Review Article | Open Access

Microbial Function on Climate Change - A Review

Endeshaw Abatenh*, Birhanu Gizaw, Zerihun Tsegaye and Genene Tefera

Department of Microbiology, Ethiopia Biodiversity Institute, Addis Ababa, Ethiopia

Abstract

Greenhouse gases concentration is increased through time within different human and natural factors. Such as the combustion of coal, oil and other fossil fuels, decay of plant matter and biomass burning. Climate change and global warming is the major problem in the world. it is damage and destroy a number of biotic componets. It have also effect in thier microbial comunity structure and function and also their metablolic activity. In order to fight/compromize/ climate change using a number of methods are listed. For example, microorganisms and biological componets have many potential role for mitigation by contribute forward response. Microorganisms have a wide potential especialy used in greenhouse gas treatment and reduction through nutrient recycling. It act as either generators or users of these gases. It provide to reduce environment hazards which is caused by nature and antropogenic activity. Generally biogeochemical cycles and climate changes are never see separately.

Keywords: Green-house gases (GHGs); Climate change; Microbial comunity; Biogeochemical cycle; Methanotropic

Introduction

The super challenges of the 21st century are climate change, energy supply, health and diseases and sustainable environment. These are hot topic today. World climate change is hot right now, intensely discussed by politicians, businessman, environmentalist, society and mass media. Microorganisms and biogeochemical cycles are the two faces for one coin. It is takes place inside oceans, soil, open and closed environment. Both are facilitate the way of making and using greenhouse gases. Microorganisms provide long and short term encouragement and discouragement feedback responses to global warming as well as climate change [1]. 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 [2,3]. Biological method to control greenhouse gas emissions is invaluable regarding to nutrients recycling. Microbial diversity in different ecosystem has many contributions in climate change controlling and fighting its negative impacts due to their metabolism is amazingly versatile and they can grow in broad environmental conditions. Microorganisms perform uptake, storage and realese of gases easly. The aim of the review is to answer what is the role of microbes playing in helping to fight climate change and greenhouse gas redaction? How will that role involve in future within mitigation option?

Climate change

Climate is defined as general or average weather conditions of a certain region, including temperature, rainfall and wind. Climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water and living things. The earth's climate is most affected by latitude, the tilt of the Earth's axis, the movements of the Earth's wind belts, the difference in temperatures of land and sea, and also topography. 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. Due to the degree of temperature increase all over the world then climate change become happened. This is causing the Earth to heat up, which is called global warming. Global warming is termed as an increase in temperature of the Earth's atmosphere in amount over a period of time. The blanket of gases that surrounds the Earth is getting much thicker. These gases are trapping more heat in the atmosphere causing the planet to warm up. 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. This is provide a blanketing effect in the lower strata of the earth's atmosphere, and this blanketing effect is being enhanced because of the human activities like burning of fossil fuels [4,5].

Causes of climate change

Greenhouse gases emission is increased dramatically in recent years due to human activity and natural factors like volcanic eruption. These gases accumulate in the atmosphere and causing concentrations to increase within time. Significant increases in all of these gases have occurred in the industrial era. The major greenhouse gases are carbon dioxide, methane, nitrous oxide and the halocarbons.

1. Carbon dioxide 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 [6]. It also turns out in deforestation.

2. Methane production is result of anthropogenic day to day activities resemble to fossil fuels production, distribution and combustion, landfills and waste, livestock farming, biomass burning and rice agriculture. Natural processes that occur in wetland termites and oceans are unique sources for methane emissions [1].

***Corresponding author:** Endeshaw Abatenh, Department of Microbiology, Ethiopia Biodiversity Institute, Comoros street 0000, Addis Ababa, Ethiopia, Tel: +251116612244; E-mail: Endeshewab@gmail.com

Received January 18, 2018; **Accepted** February 08, 2018; **Published** February 15, 2018

Citation: Abatenh E, Gizaw B, Tsegaye Z, Tefera G (2018) Microbial Function on Climate Change - A Review. Environ Pollut Climate Change 2: 147. 10.4172/2573-458X.1000147

3. Nitrous oxide is occurred during fertilizer use and fossil fuel burning. In another hand, naturally in soil and ocean also released [7].

4. Halocarbon gases quantity is increased primarily due to human and natural processes. Halocarbons are contained chlorofluorocarbons (CFC-11 and CFC-12) which were used extensively as refrigeration agents and in other industrial processes before their presence in the atmosphere were found to cause stratospheric ozone depletion. Now a day, the abundance of chlorofluorocarbon gases is decreasing as a result of international regulations designed to protect the ozone layer.

5. 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.

6. 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.

7. Aerosols are small particles present in the atmosphere with widely vary in size, concentration and chemical composition. Some aerosols are emitted directly into the atmosphere while others are formed from emitted compounds. Aerosols contain both naturally occurring compounds and those emitted as a result of human activities. 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, sulphate and dust aerosols produced by volcanic eruptions [5,8-10].

Effects of climate change on microorganisms

Climate change is forward direct and indirect effect on speed up or slows down terrestrial microbial community composition and their functions. The effect of climate change on microorganisms are listed: death and disturbance, metabolic activity is direct and indirect highly influenced, reduction/stimulation of biomass, diversity and composition leads to extinct/shift, having negative or positive result on its physiology and greenhouse gases emission. As the temperature increases microbial community structures are altered and processes like respiration, fermentation and methanogenesis are also accelerated. The impact of climate change for biotic and abiotic components are the risk of injury, illness, death from the resulting heat waves, wildfires, intense storms, floods rises, distinction, natural disasters, extreme heat, poor air quality, drought, spreading and emerging diseases are included. The effect of bacteria, fungus, algae and archea on climate change: accelerate global warming through organic matter decomposition and finally increase the flux of CO_2 in atmosphere [11-15]. Microbial decomposition of soil carbon is producing a positive feedback to rising global temperatures. Microbial biomass and enzymes is powerful tool to stimulate warming because decompose carbon based organic matter efficiently and release toxic compounds to environment. At the same time, prevent climate change. Temperature directly affects enzyme activity and microbial physiological property. Efficiency of soil microorganisms in using carbon determines the soil carbon response to climate change [16-19].

Mechanisms to Solve Climate Change

Microbial processes have a central role in the global fluxes of the key biogenic greenhouse gases (carbon dioxide, methane and nitrous oxide) and are likely to respond rapidly to climate change. Microorganisms regulate terrestrial greenhouse gas flux. This involves consideration of the complex interactions that occur between microorganisms and other biotic and abiotic factors. The potential to mitigate climate change by reducing greenhouse gas emissions through managing terrestrial microbial processes is a tantalizing prospect for the future. It is widely accepted that microorganisms have played a key part in determining the atmospheric concentrations of greenhouse gases [1,20]. The major feedback response mechanism for climate change by changing their microbial community structure and composition solve this kind of environmental problem simply, using nutrient cycling processes and stimulating their functional genetic material for degrading and eliminating chemicals or gasses which leads to global warming [21]. When microbial communities and biogeochemical cycles are linked together act as a good mechanism to solve climate change. Microorganisms are very important to use greenhouse gases as energy source and build their cell [1].

Microbial communities 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. Large amounts of organic carbon are currently locked in high latitude permafrost, grassland soils, tropical forests and other ecosystems. In another hand, 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 [12]. Microorganisms are slow down global warming and implications for crucial ecological processes such as nutrient cycling which rely on microbial activity. 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. The terrestrial carbon cycle is dominated by the balance between photosynthesis and respiration. 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. Practically, microorganisms use carbon for their metabolism substrate due to these highly consumes atmospheric carbon dioxide.

The terrestrial carbon cycle with the major processes mediated by soil microorganisms (Figure 1). Soil microorganisms essential for transfer carbon between environmental compartments to fulfill their fundamental goal mainly to achieve survival through reproduction. Thus, microbes utilize different organic and inorganic forms of carbon as carbon and energy sources. The terrestrial carbon cycle is dominated by the balance between photosynthesis and respiration [22-24]. Carbon is also found in the earth's crust, primarily as limestone and kerogens.

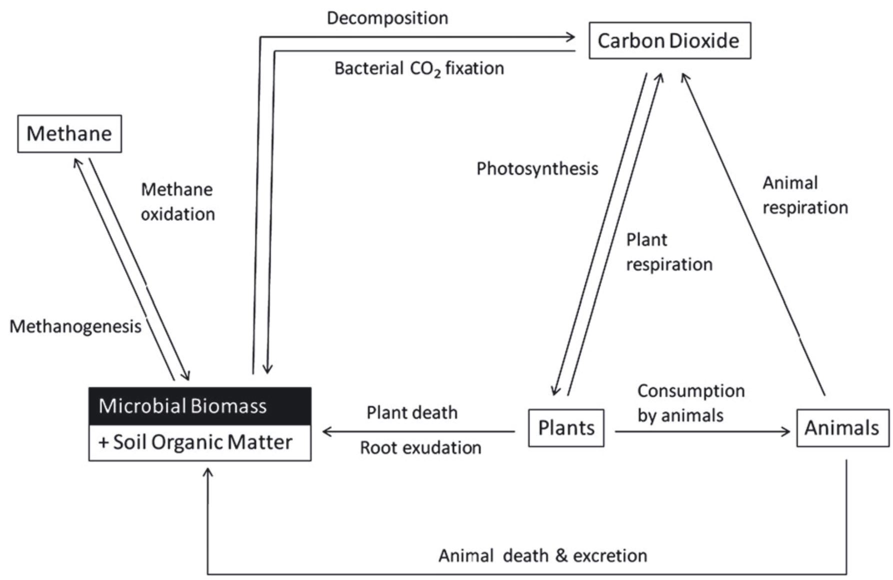

Figure 1: Microbial communities and carbon cycle.

Chemoautotrophic is an organism obtaining its nutrition through the oxidation of non-organic compounds (or other chemical processes); as opposed to the process of photosynthesis. Carbon in the earth's atmosphere exists in two main forms: carbon dioxide and methane. Carbon dioxide is dissolve directly from atmosphere in to water bodies. In addition to this, dissolving in precipitation as raindrops fall through the atmosphere. When dissolved in water, carbon dioxide reacts with water molecules and forms carbonic acid which is contribute to ocean acidity. Microorganisms are part of a larger cycling of carbon that occurs on the global scale. The actions of microorganisms help extract carbon from non-living sources and make the carbon is available to living organisms (including themselves). Much of the carbon that enters the carbon cycle is carbon dioxide. This form of carbon exists as a gas in the atmosphere, but before it can be incorporated into living organisms it must be transformed in to usable organic form. The transformative process by which carbon dioxide is taken up from the atmospheric reservoir and "fixed" into organic substances is called carbon fixation. The best known example of carbon fixation is photosynthesis, a process by which energy derived from sunlight is harnessed to form organic compounds. Photosynthetic algae are important microorganisms in this regard and chemoautotrophs are mentioned. Primarily, bacteria and archae are capable of carbon dioxide conversion in to sugar form available for cell building. Some organic carbon is returned to the atmosphere as CO_2 form during respiration. The rest of the organic carbon may cycle from organism to organism through in food chain. When an organism dies, it is decomposed by bacteria and its carbon is released into the atmosphere or the soil. CO_2 dissolves in the water at that time algae, plants and bacteria convert into organic carbon. Carbon may transfer between organisms from producers to consumers. Their tissues are ultimately broken down by bacteria and CO_2 is released back into the ocean or atmosphere [20,25]. The cycling of carbon by variety of bacteria and fungi occurs in aquatic habitats. Even relatively oxygen-free zones such as in the deep mud of lakes, ponds and other water bodies can be regions where the anaerobic conversion of carbon takes place. Both types of conversion take place in the presence and the absence of oxygen. Algal involvement is an aerobic process. In anaerobic environments, microorganisms can cycle the carbon compounds to yield energy in a process known as fermentation. Other microorganisms are able to participate in the cycling of carbon. For example green and purple sulfur bacteria are able to use the energy they gain from the degradation of a compound called hydrogen sulfide to degrade carbon compounds. Other bacteria such as *Thiobacillus ferrooxidans* uses the energy gained from the removal of an electron from iron containing compounds to convert carbon. The anaerobic degradation of carbon is done only by microorganisms. This degradation is a collaborative effort involving numerous bacteria such as *Bacteroides succinogenes*, *Clostridium butyricum* and *Syntrophomonas sp.* This bacterial collaboration is termed interspecies hydrogen transfer and finally responsible for bulk of carbon dioxide and methane is released in to atmosphere.

Microbial communities and methane cycle

Cycling of carbon between carbon dioxide and organic compounds are considered as ecologically significant. Both eukaryotes (such as plants and algae) and autotrophic bacteria (such as cyanobacteria) are contributing a great significance role in the fixation of carbon dioxide into organic compounds. As well as consumers are used organic compounds and release carbon dioxide. Methane (CH_4) is 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 [26-28]. Methanotrophic bacteria are consuming methane as their only source of energy and convert it to carbon dioxide during their digestive process. These bacteria can consume huge amount of methane which is helpful in reducing methane emission from methane producing factories and landfills [8,29]. Microorganisms are used high amount CH_4 compounds which are found at everywhere [30]. 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

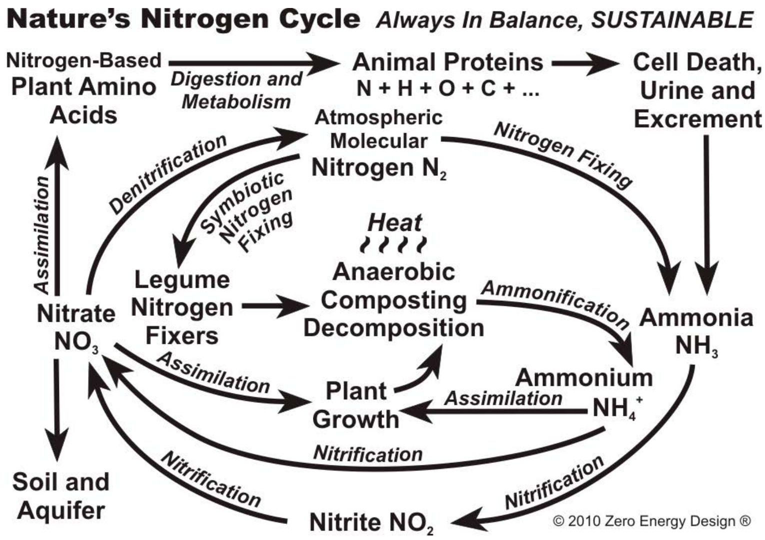

Figure 2: Nitrogen cycle.

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. Methanotrophs tend to live at the boundary between aerobic and anaerobic environments. They have access to the methane produced by the anaerobic methanogenic bacteria, but also access to the oxygen needed for their conversion of the methane [31].

Microbial communities and nitrogen cycle

Nitrogen in 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 per cent of the weight of a nodule may be bacteria. The plant supplies energy and nutrients for bacteria; bacteria and fungus supply nitrogen from the air in a form the plant can use through fixation. This is an example of symbiotic nitrogen fixation [32,33]. Specific bacteria (*Rhizobium trifolium*) possess nitrogenase 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 [34]. Nitrogen cycle mainly the conversion of nitrogen from one state to another state. Most of the time microorganisms push the system in order to harvest energy or to accumulate nitrogen in a form needed for their growth and development. Common steps for N_2 cycle: (Figure 2)

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 [32,35].

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 [32,36-38].

3. 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 [39].

4. 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 & 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 [32,39].

5. 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. 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 [32,40].

Some mitigation options used for solving climate change

1. Less chemical consumption on farms through a reduced need to spray crops.
2. Minimize introducing synthetic chemical fertilizer in agriculture and using plant promoting microorganisms which act as a biofertilizer in a form of bio inoculation. Finally, can easily stop GHSs emission.
3. Avoiding the use of fossils raw materials and fuel (wood) through replacement the use of enzymes and microorganisms helps to make bio based products in adverse variety of industry sectors.
4. Using biofuel and apply bio based strategies and targets. For example, bioethanol. Biofuels are made from living things or the waste that they produce. One of the most common biofuels is ethanol, it is produced from plants. As a result biofuels from food stuffs such as sugar cane are not likely to provide a long term solution as a replacement to fossil fuels. The sugar can then be fermented (broken down) to ethanol by microbes such as the yeast *Saccharomyces cerevisiae*, *Sulfolobus solfataricus* and *Trichoderma reesei.*
5. Using potential bio based chemicals and plastics because of can replace their fossil based counter parts with significant and proven in greenhouse gases emission reduction.
6. Introduce novel species in the ecosystem are necessary.
7. Improving drought tolerance biotic organisms.
8. Minimizing and reducing water loss from agriculture.
9. Apply afforestation program all over the world. Then carbon sequestration an easily managed.

Conclusion

Generally, microorganisms through nutrient cycling act as a break down organic matter release greenhouse gases and speed up global climate change. In another side, it minimizes or compromises the emission of different gases and slows down or prevents climate change by converting to organic form usable for themselves and others. In ecological processes microbes have significant value in consumption/ transformation and production of gases. Biological mechanisms are regulating carbon and nitrogen exchanges between the land, water and atmosphere. Microbial ecology to assess terrestrial carbon cycle play important role for balance ecosystem and stabilize atmospheric condition. Methylotrophs can use greenhouse gases as substrates to fulfill their energy and carbon needs. Greenhouse gases are moving forward to atmosphere during respiration (breathing), decay and combustion (burning). Nature also by itself does a great job of balancing the carbon and nitrogen with in biogeochemical nutrient cycling.

Recommendation

For best clarity further scientific investigation on how microorganisms use and produce GHGs will respond to climate change should be conducted.

Conflict of Interest

Authors did not declare any conflict of interest.

Acknowledgment

I would like to thank Ethiopian biodiversity institute and my colleague to provide support and opportunity to work this review.

References

1. Singh BK, Bardgett RD, Smith P, Dave SR (2010) Microorganisms and climate change: Terrestrial feedbacks and mitigation options. Nat Rev Microbiol 8: 779-790.
2. Joshi PA, Shekhawat DB (2014) Microbial contributions to global climate changes in soil environments: Impact on carbon cycle. Ann Appl Biosci 1: 7-9.
3. Pradnya A. Joshi, Dhiraj B. Shekhawat (2014) Microbial contributions to global climate changes in soil environments: Impact on carbon cycle. Ann Appl Biosci 1: 7-9.
4. Venkataramanan M, Smitha (2011) Causes and effects of global warming. Indian J Sci Technol 4: 226-229.
5. Olufemi A, Reuben O, Olufemi O (2014) Global climate change. J Geosci Environ Protect 2: 114-122.
6. Davidson EA, Janssens IA (2006) Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature 440: 165-173.
7. Sanford RA, Wagner DD, Cu QW, Chee-Sanford J, Thomas SH, et.al. (2012) Unexpected non-denitrifier nitrous oxide reductase gene diversity and abundance in soils. Proc Natl Acad Sci 109: 19709-19714.
8. Charu G, Prakash D, Sneh G (2014) Role of microbes in combating global warming. Int J Pharm Sci Lett 4: 359-363.
9. Lal R (2005) Forest soils and carbon sequestration. Forest Ecol Manage 220: 242-258.
10. Hasin AAL, Gurman SJ, Murphy LM, Perry A, Simth TJ, et al. (2010) Remediation of chromium (VI) by a methane-oxidizing bacterium. Environ Sci Technol 44: 400-405.
11. Swati T, Ramesh S, Shaily J (2014) Effect of climate change on plant-microbe interaction: An overview. Eur J Mol Biotechnol 5: 149-156.
12. Weiman S (2015) Microbes help to drive global carbon cycling and climate change. Microbe Mag 10: 233-238.
13. Castro HF, Classen, AT, Austin EE, Norby RJ, Schadt CW (2010) Soil microbial community responses to multiple experimental climate change drivers. Appl Environ Microbiol 76: 999-1007.
14. Fierer N, Schimel JP (2003) Proposed mechanism for the pulse in carbon dioxide production commonly observed following the rapid rewetting of a dry soil. Soil Sci Soc Am J 67: 798-805.
15. Bardgett RD, Freeman C, Ostle NJ (2008) Microbial contributions to climate change through carbon cycle feedbacks. ISME J 2: 2805-2814.

16. Allison SD, Wallenstein MD, Bradford MA (2010) Soil carbon response to warming dependent on microbial physiology. Nat Geo Sci 3: 336-340.

17. Friedlingstein P (2006) Climate carbon cycle feedback analysis: Results from the C_4MIP model intercomparison. J Clim 19: 3337-3353.

18. Steinweg JM, Plante AF, Conant RT, Paul EA, Tanaka DL (2008) Patterns of substrate utilization during long-term incubations at different temperatures. Soil Biol Biochem 40: 2722-2728.

19. Bradford MA, Davies CA, Frey SD, Maddox TR, Melillo JM, et al. (2008) Thermal adaptation of soil microbial respiration to elevated temperature. Ecol Lett 11: 1316-1327.

20. Zimmer C (2010) The microbe factor and its role in our climate future. Yale Environ.

21. Zhou J, Xue K, Jianping X, Ye Deng, Liyou Wu, et al. (2011) Microbial mediation of carbon-cycle feedbacks to climate warming. Nat Clim Change 2: 106-110.

22. Prosser JI (2007) Microorganisms cycling soil nutrients and their diversity. Modern Soil Microbiol 237-261.

23. Christos G, Joanna MC, Liz JS (2014) The role of soil microbes in the global carbon cycle: Tracking the below-ground microbial processing of plant derived carbon for manipulating carbon dynamics in agricultural systems. J Sci Food Agric 94: 2362-2371.

24. Falkowski PG, Fenchel T, Delong EF (2008) The microbial engines that drive earth's biogeochemical cycles. Science 320: 1034-1039.

25. Crowther TW, Thomas SM, Maynard DS, Baldrian P, Covey K, et al. (2015) Biotic interactions mediate soil microbial feedbacks to climate change. Proc Natl Acad Sci 112: 7033-7038.

26. Semrau JD, DiSpirito AA, Yoon S (2010) Methanotrophs and copper. FEMS Microbiol Rev 34: 496-531.

27. Nikiema J, Bibeau L, Lavoie J, Brzezinski R, Vigneux J, et al. (2005) Biofiltration of methane: An experimental study. Chem Eng J 113: 111-117.

28. Bousquet P, Ciais P, Miller JB, Dlugokencky EJ, Hauglustaine DA, et al. (2006) Contribution of anthropogenic and natural sources to atmospheric methane variability. Nature 443: 439-443.

29. Shindell D, Johan CI, Kuylenstierna, Elisabetta V, Rita VD, et al. (2012) Simultaneously mitigating near-term climate change and improving human health and food security. Science 335: 183-189.

30. Zimmerman L, Labonte B (2015) Climate change and the microbial methane banquet. Clim Alert 27: 1-6.

31. Parul Rajput, Rupali S, Gourav M, Mohanty SR, Archana T (2013) Biogeochemical aspect of atmospheric methane and impact of nanoparticles on methanotrophs. J Environ Anal Toxicol 3: 2-10.

32. Anne B (2010) The nitrogen cycle: Processes, players and human impact. Nature Education Knowledge 2: 1-9.

33. Vitousek PM, Menge DNL, Reed SC, Cleveland CC (2013) Biological nitrogen fixation: Rates, patterns and ecological controls in terrestrial ecosystems. Philos Trans R Soc Lond B Biol Sci 368: 1-9.

34. Jama Bashir, Ndufa JK, Buresh RJ, Shepherd KD (2013) Vertical distribution of roots and soil nitrate: Tree species and phosphorus effects. Soil Sci Soc Am J 62: 280-286.

35. Orr CH, James A, Leifert C, Cooper JM, Cummings SP, et al. (2011) Diversity and activity of free-living nitrogen-fixing bacteria and total bacteria in organic and conventionally managed soils. Appl Environ Microbiol 77: 911-919.

36. Ward BB (2011) Measurement and distribution of nitrification rates in the oceans. Methods Enzymol 486: 307-323.

37. Kim SW, Miyahara M, Fushinobu S, Wakagi T, Shoun H (2010) Nitrous oxide emission from nitrifying activated sludge dependent on denitrification by ammonia-oxidizing bacteria. Bioresour Technol 101: 3958-3963.

38. Wunderlin P, Mohn J, Joss A, Emmenegger L, Siegrist H (2012) Mechanisms of N_2O production in biological wastewater treatment under nitrifying and denitrifying conditions. Water Res 46: 1027-1037.

39. Ram KS, Shwetang K (2014) Review on changing natural nitrogen cycle: Special reference to Kingdom of Saudi Arabia. Intr J Eng Sci Inven Res Dev 1: 73-80.

40. Groffman P (2012) Terrestrial denitrification: Challenges and opportunities. Ecol Proc 1: 1-11.