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Review Article

CLIMATE CHANGE IMPLICATIONS ON MICROBES AND RESPONSES

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ABSTRACT
Climate change is currently one of the most discussed problems of the present times. However, the role of and consequences on microorganisms in this regard has not received due attention. In fact, the microbial aspect of climate change is absent from several climate change models, even though it an important driver and respondent of the same. Therefore the present review has been attempted to study how microbes influence climate change and how they are in turn affected by the phenomenon. It also tries to reveal the various feedbacks which the microbes exhibit with regards to climate change. Through the review it was found that both terrestrial and aquatic microbes play a significant role in climate change and that many aspects of the microbial world has not yet been studied in this regard. It is therefore high time to recognize the relevance of these organisms to the issue.

KEYWORDS: Climate change, Microbes, Impacts, Role.

INTRODUCTION
Climate change is among the most complex global issues of the present times and encompasses scientific, economic, social, political, moral and ethical aspects (NASA, 2015a). A crucial entity in this context is the microbial world, which is involved in carbon and nitrogen cycles as well as and in the production and consumption of greenhouse gases such as carbon dioxide and methane (Microbiology Online, 2015). In fact microbes have been responsible for producing and removing greenhouse gases ever since they first evolved in the ocean more than 3.5 billion years ago and moved to land about 2 billion years ago (Zimmer, 2010). These organisms have played an important role in the determination of atmospheric concentrations of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) throughout much of earth's history (Singh *et al.*, 2010).
Photosynthetic microbes remove carbon dioxide from the atmosphere, whereas the heterotrophic microbes produce greenhouse gases by decomposing organic matter. This determines the net carbon flux, which varies among different ecosystems, according to climatic conditions such as temperature. Microbial responses are thus a key component of carbon flux for the planet (Weiman, 2015). This is because microbes not only lock up but also release huge amounts of carbon (Zimmer 2010). Greenhouse gases like CO_2 and CH_4 and N_2O have predominantly microbial basis (Singh et al., 2010).
Micro-organisms have influenced the earth's climate which in turn has influenced them (Zimmer, 2010). However, the role of microbes is overlooked in most discussions of climate change (Dupré, 2008; Walsh, 2015). But, being a critical part of carbon and other biogeochemical cycles, the responses of the microbial world to the phenomenon require attention (Walsh, 2015). These organisms have several positive and negative feedback responses to climate change, the magnitudes of which have not been adequately understood. It is in fact, this lack of knowledge due to which microbial activity is absent from most climate change models (Dupré, 2008). Taking all the above facts into consideration, the present review has been attempted to understand the role of terrestrial and aquatic microbes with respect to climate change and how they are affected by the phenomenon. In this way, the review tries to establish the microbial aspect of the biosphere as an important determinant and respondent of climate change. It thus tries to highlight significant issue much relevant to the present world which has always been neglected.

ROLE OF MICROBES IN CLIMATE CHANGE
Role of terrestrial microbes
Soil microbes release 7.5 to 9 times more atmospheric carbon through decomposition as compared to anthropogenic emissions worldwide annually (Crowther *et al.*, 2015). In fact, micro-organisms that decompose plant organic matter into soil release 55 billion tons of carbon dioxide per year (*i.e*. eight times more than humans) (Zimmer, 2010). This in turn influences the carbon cycle-climate feedback, based on which the Intergovernmental Panel makes projections on climate change. Biotic interactions in soil are important in this regard as they play an important role in mediating soil microbial feedbacks to climate change (Crowther *et al.*, 2015). However, decomposition of organic matter is highly sensitive to global trends in climatic factors (Crowther *et al.*, 2015). Global emission of CH_4 is more directly controlled by microorganisms than that of CO_2 (Singh *et al*., 2010). These organisms, in fact, account for about 85% of world methane

production (Zimmerman and Labonte, 2015). In this regard, mention can be made of spongy bog soils, where several microbial genes and proteins are involved in the production of methane. An example of such enzyme is methylcoenzyme M reductase, which transforms carbon dioxide into methane. Warming trends are likely to drive local microbes to produce even larger amounts of methane (Svoboda, 2015a). On the other hand, microbial nitrification and denitrification is responsible for the release of huge quantities of N_2O. For each tone of reactive nitrogen (mainly fertilizer) deposited, 10–50 kg are emitted as N_2O (Singh *et al*., 2010).

Micro-organisms are also responsible for the consumption of about 60% of methane produced worldwide (Zimmerman and Labonte, 2015). Such methane-consuming microorganisms, which are capable of removing atmospheric methane even at very low concentrations, are present in both on land and in the sea (Zimmerman and Labonte, 2015). Thus, microbes also help in controlling climate change. In this regard, mention can also be made of the microbes of native prairie grasslands, which play an important role in stabilizing carbon flux. However, these microbes are affected by changing precipitation patterns that occur due to climate change. This is likely to have major effects on the carbon balance in such ecosystems through impacts on soil carbon storage (Weiman, 2015).

In the context of the role of terrestrial microbes in climate change, permafrost in the polar region which is the largest terrestrial store of carbon compounds (Weiman, 2015), needs a special mention. Permafrost covers nine percent of global landmass but contains 25 to 50% world soil organic carbon (European Commission, 2015). About 1,700 gigatons of carbon are stored in permafrost whereas the earth's atmosphere contains about 850 gigatons of carbon (Atkin, 2015). In fact, the tundra of North America and Siberia has stored carbon for the past 11,000 years, since the glaciers retreated at the end of the last Ice Age (Zimmer, 2010).

However, as the temperature increases due to climate change, melting of the inert permafrost soil layers occur. As a result the dormant microbial community in these structures is altered and processes like respiration, fermentation, and methanogenesis are accelerated (Weiman, 2015). Bacteria in the thawing soil layer start producing several proteins and enzymes that break down long chains of carbon molecules like plant cellulose into simpler sugars that the bacteria use as a source of energy (Svoboda, 2015a). In fact, as the soil thaws, it starts to transition more into decomposition (Svoboda, 2015a). Such processes convert soil carbon into greenhouse gases such as carbon dioxide and methane (Weiman, 2015).

Soil microbes obtain energy either from acetate produced plants, or from carbon dioxide and hydrogen and produce methane in the process. The initial methane flux does not come from the former pathway. But as the frozen soils

gradually into wetlands, acetate becomes the preferred carbon source (University of Arizona, 2014). As the Arctic becomes warmer and drier, the microbes within the permafrost are first expected to produce carbon dioxide. But as environmental conditions change, the microbes would produce methane (Atkin, 2015). Therefore, as vast areas of Arctic and alpine tundra heat up due to climate change, increasing quantities of methane are produced from permafrost soils, mainly due to the presence of methane-producing archaea. However, the balance between these processes and other methane-consuming sources has not been properly understood (Dupré, 2008). Hence, Arctic carbon has been identified as both a potential symptom and driver of global warming (European Commission, 2015). This is a serious issue as permafrost of Greenland has become active with the warming up of the climate (Atkin, 2015). Approximately 120 gigatons of carbon (without considering microbes) has been estimated to be released from thawing permafrost by 2100. This would increase the average global temperature by 0.29 degrees. Thereafter, if the climate worsens, total permafrost emissions are likely to almost double. This is particularly significant because these emissions from permafrost are irreversible (Atkin, 2015). The microbe *Methanoflorens stordalenmirensis* is crucial in this regard as it releases enormous quantities of carbon stored in Arctic permafrost as methane. This organism in fact plays an important role in determining the fate of the entire ecosystem (Zolfagharifard, 2014). The species was discovered in permafrost soils in northern Sweden that had thawed under the effect of globally rising temperatures (University of Arizona, 2014).

Role of aquatic microbes

The oceans store about 93% of the world's carbon dioxide and cycle about 90 billion tonnes of carbon dioxide per year; whereas approximately six billion tonnes are generated by human activities. Micro-, nano-, and pico-planktons, including bacteria and archaea dominate the mechanics of the oceanic carbon cycle (Stewart, 2003). Oceans, especially in polar areas (*e.g.* arctic sea ice), harbor enormous populations of photosynthetic microorganisms which remove huge quantities of atmospheric carbon. In fact, oceanic microbes have been responsible for sequestering about one-fourth of anthropogenic carbon dioxide generated since 1960. About 40% of this amount has been removed by the Southern Ocean, mostly by physical processes (Weiman, 2015). In addition, tropical river plumes also capture atmospheric carbon (Weiman, 2015). A formidable population (approximately 4×10^{30}) of viruses also dwells in ocean waters, which could lyse upto 50% of oceanic bacteria every day. Thus, they significantly affect global geochemistry by altering the accumulation and respiration of organic material; an important determinant of climate change (Suttle, 2007). Methano-trophic bacteria act as a buffer against the huge amounts of CH_4 produced under some environments (Singh *et al*., 2010). For instance, they consume enormous quantities of methane that arise from marine sediments as well as abrupt well blowouts like the Deepwater Horizon spill (Zimmerman and Labonte, 2015). In fact, marine environments are a formidable source methane emission to the atmosphere as this greenhouse gas constantly leaks out of holes on the ocean floor. However, every such methane seep has its own unique community of methane-eating microbes as there is no universal species that is distributed throughout the entire deep sea at these areas. The surrounding microbes remove about 75% of the methane before it enters into the atmosphere. These organisms thus play an important role in maintaining the climate by controlling greenhouse gas emissions (Trinastic, 2015). Natural emissions (~250 million tonnes of CH_4 per year) are dominated by microbial methanogenesis by anaerobic archaea in wetlands, oceans, rumens and termite guts (Singh *et al*., 2010). However, it must be added that landscape characteristics are important factors that determine microbial greenhouse gas emissions and carbon storage. For instance, saltier wetland areas attract microbial communities that emit lesser amounts of methane, as compared to areas where water flows actively (Svoboda, 2015b). Another important other factor is this regard is the state of water bodies. Wetlands which have been restored have been found to harbor microbial communities that produce methane at higher rates than those which are undisturbed wetlands. Increased rates of plant growth in restored wetlands are likely to accelerate biological processes that release methane (Svoboda, 2015b). The worldwide balance of methane is determined by methanogenic (methane-producing) microbes like Archaea that exist in sediments beneath the sea-bed, freshwater lakes and wetlands as well as in deep in oxygen-free soils; methanotrophic Archaea (methane consumers), that are present in marine sediments and consume approximately 90% of ocean methane and methane-oxidizing bacteria of soil and water that consume methane using oxygen (Zimmerman and Labonte, 2015).

However, microorganisms can also accelerate a positive feed-back for climate change. This can be exemplified by the fact that when Arctic sea ice melts, the dark surfaces of marine phytoplanktons absorb greater amounts of solar radiation, which could warm the waters bodies up to 20 % more than what current climate models predict. Under worst circumstances, up to a tenth more sea ice could disappear and there could be about 50 more ice-free days during summers (Piotrowski, 2015).

IMPACTS OF CLIMATE CHANGE ON MICROBES

Microbes vividly exhibit responses towards biotic and abiotic factors (Kardol *et al*., 2010). Therefore, micro-organisms precisely respond to climate change. They also display feedback responses to greenhouse gas flux, which is both positive and negative (Singh *et al*., 2010).

Impacts on terrestrial microbes

The components of climate change factors like higher levels of atmospheric CO_2, modified temperature patterns and warming, exert direct as well as indirect effects on soil microbial communities (Castro *et al*., 2010). In fact, complex changes in microbial community occur in terrestrial ecosystems due to climate change which modifies several factors simultaneously (Castro *et al*., 2010). Such alterations in the bulk soil micro-organisms under the influence of climate change can have significant consequences on plants as well as the state of soil carbon balance (Classen *et al*., 2015). However, interactions of different variables of climate change drivers can be selective for particular soil microbes and the resulting changes in community are likely to determine the function of ecosystems in the future (Castro *et al*., 2010). Microbial groups have their specific temperature ranges for growth and activity and hence increased temperature can affect the composition of the microbial community (Fierer and Schimel, 2003; Singh *et al*., 2010). With the elevation of temperatures, the processing, turnover and activity of microbes increases. Consequently, shifting of microbial community takes place in favor of the species that are adapted to higher temperatures and have accelerated rates of growth (Castro *et al*., 2010). This can be exemplified by the effect of climate change on two key topsoil cyanobacteria *viz*: *Microcoleus vaginatus* and *Microcoleus steenstrupii* in arid topsoils of western United States. The latter, which is thermo-tolerant, has been found to outcompete and even replace the former which is psychro-tolerant as global temperatures surge. These bacteria are critical for maintaining the microbial population of the topsoil, the characteristics of which are crucial for controlling soil erosion (DiGregorio, 2015). Thus, it is understood that climatic change alters the relative abundance and function of soil microbial communities because these microbes differ in terms of physiology, temperature sensitivity and growth rates. This in turn has a direct effect on the regulation of the specific processes which are mediated by these organisms (Classen *et al*., 2015). Such changes in the composition of microbial community, triggered by warming, can also bring about the depletion of available substrate (Schindlbacher *et al*., 2011). In this regard, it must be mentioned that both fungal as well as bacterial abundance are likely to be affected by warming (Schindlbacher *et al*., 2011).

Warming increases microbial maintenance and thus microbial maintenance demand (respiration per biomass) increases (Anderson and Domsch, 2010). Thus, global changes such as temperature increase can directly alter the rates of respiration of soil microbes because of the temperature sensitivity of microbial metabolism and the processes they are mediate (Classen *et al*., 2015). However, microbial community composition and adaptations which determine an increase in soil respiration are unlikely to occur until other variables like substrate and moisture become limited or composition/structure of the forest stand is altered (Schindlbacher *et al*., 2011). Warming also alters decomposer physiology and consequently the CO_2 efflux from soil (Schindlbacher *et al*., 2011). In fact, rising temperatures are likely to accelerate decomposition by fungi, resulting in an elevated release of carbon dioxide from soil. But increased temperature also increases soil nitrogen levels that decrease fungal decomposition rates. The greater nitrogen availability, in turn suppresses microbial activity and diversity (American Society for Microbiology, 2008). On the other hand in bacteria, biochemical reactions under the stress of warmer climate run less efficiently. Therefore, instead of converting much of the carbon in plants into biomass, microbes release more of it as carbon dioxide (Zimmer, 2010). The absorption of higher amounts of carbon dioxide, thus produced, in turn, triggers plants to release nitrous oxide and methane (Center for Ecosystem Science and Society, 2011). However, the overall response to warming by microbes in terms of soil organic matter decomposition depends upon temperature sensitivity of the decomposers, availability of substrate, interactions with above-ground processes and environmental variables like soil moisture and potential physiological adaptations (Schindlbacher *et al*., 2011).

Under-snow microbial activity in coniferous forests is also affected by temperature increase arising from climate change. This activity is remarkably high in late winter as the snowpack provides extremely low temperature, which is required for the development of snow molds. The molts contribute to about 10-30% of the total annual carbon dioxide production in these areas. Rising temperatures are likely to shorten the late winter period of subfreezing temperatures. Due to warm soils, the snow molds would produce less carbon dioxide. But this would also result in mortality of trees, which depend on snow melt water, leading to an overall decrease in carbon fixation (American Society for Microbiology, 2008).

Climate change increases the risk of both drought and flooding due to extreme precipitation. The timing of snowmelt is also altered. Thus, the overall availability of water is affected (US EPA, 2015d). These changes have significant consequences as moisture not only determines terrestrial microbial community structure but also the soil decomposition rate (affected by 20% increase or decrease in precipitation). Soil drying increases availability of oxygen and enhances carbon cycling in wetlands and peat-lands, thereby increasing CO_2 flux (Fierer and Schimel 2003; Singh *et al*., 2010). In fact, among the various factors of climate change and their impacts alter the overall abundance of bacteria and fungi, changes in precipitation regimes exert the greatest effect on the community composition (Castro e*t al*., 2010). Depending upon the factors that limit productivity of ecosystems, alterations in precipitation and soil moisture could either increase or decrease the ratio of bacteria and fungi and induce shifts in their community composition (Schimel *et al*., 1999; Williams *et al*., 2007; Chen *et al*., 2007).

Higher levels of atmospheric carbon dioxide causes soil microbes to release more potent greenhouse gases methane and nitrous oxide (Pathak and Pathak, 2012). In fact, Elevated CO_2 levels not only increases CH_4 efflux but also substantially decreases methane uptake by soil microorganisms (up to 30%) (Phillips *et al*., 2001; Ineson *et al*., 2008). In addition, increased levels of carbon dioxide, arising from human activity, also causes distinct and important shifts in the microbial communities in trees leaves and decomposing leaves in streams. This could have enormous impacts on the food chain as these microbes are a source of nutrients for the small phytophagous animals (American Society for Microbiology, 2008).

In comparison to above-ground vegetation, soils are protected from climatic fluctuations and events (Dura´n *et al*., 2014). However, the indirect consequences of climate change propagate through plants on the associated soil communities (Kardol *et al*., 2010). In fact, below-ground communities are structured by the effect of environmental conditions on associated vegetation (Fierer and Jackson, 2006). The indirect impacts of climate change that occur as a result of plant community shifts could not only be different from the direct impacts but also at times counteract the latter (Kardol *et al*., 2010).

When the levels of CO_2 increase, the release of labile sugars, organic acids and amino acids from plant roots is altered quantitatively and qualitatively. Microbial, dominance, diversity growth and activity are affected accordingly and depending upon the availability of nutrients (such as nitrogen), changes in CO_2 flux occur (Diaz *et al*., 1993; de Graaff *et al*., 2006; Bardgett *et al*., 2009). In addition, plant feedback to CO_2 also affects soil microbial respiration physiology (Singh *et al*., 2010).

Plants exude carbon-rich liquids that are consumed by microbes. Consequent to stress, such as temperature, the type of such secretions change, which in turn, alters the chemicals secreted by the microbes (Ngumbi, 2015). Indirect consequences can also take place due to modification of soil pathogenic activities of plants expanding ranges under climate change (Engelkes *et al*., 2008, Morrie¨n *et al*., 2011). In addition, higher induced levels of defensive compounds such as polyphenols in such plants could affect litter input quality, which in turn changes the composition and activity of decomposer community (Engelkes *et al*., 2008). The phenology of roots and shoots change due to climate change and as a result altered interactions in the rhizosphere interactions influence the distinct seasonal assemblages of soil microbes (Classen *et al*., 2015). Plant functional traits are also altered due to changes in microbial diversity (*e.g*., Lau and Lennon, 2011). In fact, soil communities that are communities remain closely associated with plants migrating to higher altitudes under the influence of temperature rise are important determinants of such transitions (Classen *et al*., 2015). On the other hand, trees and shrubs that advance northward in the tundra under the influence of warmer temperatures can also influence microbes in unpredictable ways by means of the shadows which they cast on the ground (Zimmer, 2010).

Impacts on aquatic microbes

The temperature of coastal waters has surged during the past century, and the warming is likely to take place by 4 to 8°F in the 21st century (US EPA, 2015b). Several vital properties of water crucial to ecosystems functions depend upon its temperature. Therefore, aquatic temperature swings can not only trigger dramatic changes in life-forms but also cause their disappearance (NASA, 2015b).

The warming up of ocean has been changing it in profound ways. In addition, the accumulation of carbon dioxide is leading to its acidification. Oceanic stratification has also arisen due to the expansion of oxygen-depleted zones. This is likely to affect the microbial food webs and consequently the biogeochemical cycles (Walsh, 2015). Due to the warming of polar ocean, the ecosystem becomes more favourable for microbes. As polar oceans warm, marine microbes become more active and consume more organic matter (Zimmer, 2010). It is however, also has been stated that as the ocean surface warms up due to increasing temperatures, its density decreases. Therefore, it floats over the cooler nutrient-rich deeper water. In the absence of an adequate supply of nutrients from below, the phytoplanktons in the upper layer starve. As a result, primary production is reduced and consequently carbon pumping to the deeper water decreases (Walsh, 2015). Cell size is an important determinant of the effect of temperature rise. In the Arctic, smaller phytoplankton species continue to flourish whereas the larger are eliminated under changing climate. This is because smaller cells have a higher surface to area ratio and hence are more efficient in acquiring nutrients. On the other hand, larger cells sink more quickly. So, it has been projected that phytoplankton cell size would decrease with global warming. Consequently, there would be a decrease in carbon pumped into the ocean interior due to the presence of smaller, more buoyant cells (Walsh, 2015).

Arctic sea ice reaches its minimum each September. September Arctic sea ice has been reducing at a rate of 13.3 percent per decade, relative to the 1981 to 2010 average (NASA, 2015b). In fact, the rate of loss of ice in Antarctica is about 134 billion metric tons annually since 2002, while the same in Greenland ice sheet is approximately 287 billion metric tons per year (NASA, 2015b). Thus, global warming has reduced the duration and extent of sea-ice in the Arctic. As a result, the abundance of ice algae that survive in the nutrient-rich ice is likely to be affected negatively. Such algae are consumed by zooplanktons, which are in turn are consumed Arctic cod, an important food source for several marine mammals like seals. Seals are eaten by polar bears. Therefore, declines in ice algae, arising due to global warming can threaten polar bear populations (US EPA, 2015c). Thus, environmental conditions under the greenhouse effect are expected to favour specific species with appropriate adaptations in the aquatic environment. This is evident in two groups of common oceanic nitrogen fixers; viz: *Trichodesmium* and *Crocosphaera*. Greenhouse conditions are likely to elevate nitrogen-fixing productivity up to 125 percent in some strains of these groups whereas inhibiting effect was found in some others (Radford, 2013).

Global warming can change the p^H of seawater as well as wind patterns, both of either slow down or accelerate microbial growth (Zimmer, 2010). This can also have far-reaching effect as when phytoplanktons in the ocean are fed by bacteria, they break down into component molecules, such as fats and lipids. These become airborne as the surface of the ocean churns and join aerosols. These later develop into the framework where drops of moisture ultimately develop into clouds. Thus, variations in specific ocean microbes, resulting from climate change, can affect the concentrations of less water-soluble molecules such as lipids in seawater and consequently the overall weather (Iacurci, 2015). Climate change can also extend the range of many harmful microbes and in this way harm biodiversity. This is evident in case of the oyster parasite, *Perkinsus marinus*. This parasite, which is capable of causing huge oyster deaths, has extended its range northward from Chesapeake Bay to Maine in USA, a 310 mile expansion due to the increase of average winter temperatures (US EPA, 2015c).

Lakes have been warming an average by 0.61 degrees Fahrenheit (0.34 degrees Celsius) every decade. These water bodies have been are losing their ice cover earlier in the spring in the northern climates. In addition, less cloud cover in many parts of the earth, have been exposing water bodies more to solar radiation (NASA, 2015b). The increase in lake temperatures occur at a higher rate in higher latitudes (NASA. 2015b). Their warming rates, which are higher than those of the ocean and atmosphere, can have severe impacts (NASA, 2015b). In fact, as a consequence, algal blooms, which decrease water oxygen levels, are projected to increase 20 percent in lakes. Algal blooms which are toxic to fish and animals are likely to increase by 5 percent. Emissions of methane are also projected to elevate by 4 percent over the next decade, if this trend continues (NASA, 2015b).

Increasing levels of carbon dioxide in the atmosphere are causing the oceans to absorb more of the gas and become more acidic. The consequent increase in acidity exerts significant impacts on coastal and marine ecosystems (US EPA, 2015b). Carbon dioxide also has the potential to control the biodiversity of keystone microbes in the ocean ecosystem (Radford, 2013). This fact can be exemplified by the bacterium *Trichodesmium* which converts nitrogen gas into consumable forms in nutrient-deficient parts of the ocean. The synthesized material is utilized by several other organisms. Elevated levels of carbon dioxide could lead to the accelerated reproduction of the microbe, resulting in excessive consumption of the nutrient as well as iron and phosphorus that are not easily available in the ocean. The resulting shortage would not only lead to the extinction of the bacterium but also severely affect the entire marine food chain, including fishes (Howard, 2015).

DISCUSSION

The climate of the earth has been stable for the past 12,000 years, a crucial requirement for human development. (NASA, 2015a). However, average world temperature surged by 1.5°F during the previous century and has been predicted to increase by another 0.5 to 8.6°F in course of the coming hundred years. Even minute alterations in the global average temperature can trigger large and violent shifts in climate and weather (US EPA, 2015a). On the other hand, the daily level of atmospheric carbon dioxide exceeded 400 ppm for the first time in human history in 2013. Such high levels were in existence about three to five million years ago in the Pliocene era (NASA, 2015a). As the climate changes, adaptability will be required, which will be difficult to achieve under accelerated rates of change (NASA, 2015a).

Microorganisms have been playing a key part in the determination of atmospheric concentrations of greenhouse gases. They are not only drivers of climate change but also respond to the phenomenon distinctly (Singh *et al*., 2010). However, although they are sensitive to global changes, their responses have not been understood (American Society for

Microbiology, 2008; Microbiology Online, 2015). This is because microorganisms live in diverse communities which interact with other organisms and the environment in complex ways (Microbiology Online, 2015). These organisms, in fact, have several positive and negative feedback responses to climate change (Microbiology Online, 2015). An example of the former is the fact that global warming has been found to accelerate the decomposition of soil organic matter and thereby increase the carbom flux from soil to the atmosphere (Trumbore *et al*., 1996; Cox *et al*., 2000; IPCC, 2007). But microorganisms can also buffer the effects of increasing atmospheric carbon dioxide levels and thereby slow down climate change (Weiman, 2015). In addition, specialized methane-producing and consuming microbes are present throughout water, soil and sediments in earth. A proper appreciation of the complex ecologies and response to climate change and other anthropogenic factors is immediately needed so that these microbial ecologies can be harnessed for climate change mitigation (Zimmerman and Labonte, 2015).

NASA classifies approaches to prevent climate change into mitigation (reducing greenhouse gas emissions and stabilizing their levels) and adaptation (adapting to the climate change that is taking place) (NASA, 2015a). For the former, all climate change parameters must be studied to be properly manipulated. But microbes, which are important factors, have not been adequately studied with respect to this issue. For instance, most of the studies of climate change on soil microbes have concentrated around gross parameters, such as biomass, activity of enzymes or basic community profiles in relation to single factors of climate (Castro *et al*., 2010). Plant interaction with soil communities, which is the most important controller of soil nitrogen and carbon dynamics, has also not been fully understood (Castro *et al*., 2010). However, it is a fact that climate change alters soil microbial communities and consequently the establishment and development of plant species. As a result, ecosystem responses are likely to change (Classen *et al*., 2015). Another important aspect is the issue of permafrost. However, thawing of Arctic permafrost can be prevented if warming is limited to a global average of 2 degrees Celsius (Atkin, 2015). About 200 countries adopted a climate agreement at the COP21 summit in Paris which aims to control the planet's average global temperature rise within 2 degrees Celsius (Shaftel, 2015).

Therefore, it is well understood that the microbial aspect of climate change is a relevant issue of the present times. The aspect needs to be properly studied and properly given due importance in discussions of global change. This is because climate change models that fail to include microbial activities are inadequate (Dupré, 2008) and it is certain that human activities have caused microbes to produce greater production of greenhouse gases (Microbiology Online, 2015).

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