Review Research Paper

Climate Change Impact on Beneficial Soil Microbial Community: A Review

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ABSTRACT

Global climate change, mainly temperature rise and increased carbon dioxide (CO_2) concentration, is a major concern these days. The inter-annual climatic variability is prominent and significantly influences the agricultural production. Soil productivity is influenced by the amount and activity of beneficial soil microorganisms, which help in degrading the organic matter as well ascertaining the availability of plant nutrients. It is essential to reduce the emission of CO_2 and other major greenhouse gases (GHGs) through the implementation of various strategies in the land use planning and by increasing the soil organic matter by adoption of various techniques which will not only help in reducing the greenhouse gas emissions and mitigating the impact of climate change on beneficial soil microbial community but also allow additional benefits to the farmers in the form of reduced labour, costs, greater efficiency, improved soil quality along with sustainable crop production.

INTRODUCTION

The soil microbial community is an important biological component of soil function, valued for its role in improving soil quality and regulating nutrient availability, and thereby influencing plant production for agriculture and other purposes (Kennedy & Smith 1995, Papendick & Parr 1992). Beneficial soil microorganisms which are the most effective geo-engineers and bio-geo-chemists play a vital role towards sustainable agriculture, which results in increased crop production and ecosystem health. As part of the microbiome, soil microorganisms could potentially play an important role in contributing to the development of ecosystem resistance to abiotic stresses, such as increased temperature and precipitation, and increasing resiliency in agricultural systems (Pankhurst et al. 1996). Soil microbial community and its functions are sensitive to changes in both temperature and water availability (Hartel 2005). The mechanisms behind temperature adaptations of soil microbes could be physiological adaptations of single species (Malcolm et al. 2008) or species shifts within the microbial community. Soil microbial communities can also affect the interaction between plants and aboveground macrofauna. For example, the presence of nematodes and microorganismal inoculants has been shown to reduce aphid populations, significant herbivores and vectors of disease (Bezemer et al. 2005). Singh et al. (2011) reviewed the role of soil microorganisms in the development of sustainable agriculture, and showed that plant growth promoting rhizobacteria (PGPR) and cyanobacteria often result in increased crop production and ecosystem health. Soil organisms contribute a wide range of essential services to the sustainable function of all ecosystems, by acting as the primary driving agents of nutrients cycle, regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emission, modifying soil physical properties and water regimes, enhancing the amount and efficiency of nutrient acquisition by the vegetation and enhancing plant health. Gram-positive and Gram-negative bacteria showed different patterns in substrate preference. Gram-positive bacteria were found to be dominant in soils with low substrate availability and in deeper soil layers (Fierer et al. 2003), while Gram-negative bacteria were found to dominate in soils with high availability of easily decomposable substrate (Kramer & Gleixner 2006). *Archaea* were found abundantly in many soils and important in methane (CH_4) and nitrogen (N) dynamics (Leininger et al. 2006).

The soil microbial community is expected to be impacted by various facets of global climate change, such as increased atmospheric CO_2, altered temperature and precipitation patterns, and increased frequency of extreme climate events (IPCC 2007).

Impact of climate change on microbial community: Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external force or due to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Microbial processes are dependent on environmental factors such as temperature, moisture, enzyme activity and nutrient availability, all of which are affected by climate change. Soil respiration is dependent on soil temperature and moisture and may increase or decrease as a result of changes in precipitation and increased atmospheric temperatures. Many ecosystems experience dramatic inter and intra-annual variability in precipitation and temperature (Craine et al. 2012). Such fluctuations in climate, from year-to-year or season-to-season, could have significant effects on soil microbial communities, directly via effects on soil moisture and temperature, or indirectly via effects on plant growth. For example, AMF (Arbuscular Mycorrhizal Fungi) composition has been shown to vary seasonally, with distinct differences between winter and summer AMF communities (Dumbrell et al. 2011). Direct effects include the influence on soil microbes due to greenhouse gas production, increased temperature, changing precipitation and extreme climatic events, whereas indirect effects result from climate-driven changes in plant productivity and vegetation structure which alter soil physicochemical conditions, the supply of carbon to soil and the structure and activity of microbial communities involved in decomposition processes and carbon release from soil. The direct and indirect impact of climate change on microbial community are shown in Fig. 1.

Temperature impact on microbial community: The average global surface temperature is predicted to increase between 1.1 and 6.4°C by 2100 and this might have an effect on soil carbon sequestration by potentially accelerating heterotrophic microbial activity (IPCC 2007). These higher temperatures, combined with variable alterations in average may lead to increased frequency, intensity and duration of droughts in the region (GCCI 2009). Soil microbial community structure and their functions are known to be sensitive to changes in both temperature and water availability (Hartel 2005). Increased temperatures accelerate the rates of microbial decomposition, thereby increasing CO_2 emitted by soil respiration and producing a positive feedback to global warming (Allison et al. 2010). Due to global warming, 25% of permafrost could thaw by 2100, making about 100 Petagram (Pg) of carbon available for microbial decomposition (Davidson & Janssens 2006). Increased thaw rates and depths in high-latitude permafrost render the large stocks of organic carbon in these soils (400 Pg, that is, 4,000 million tonnes) may be vulnerable to increased decomposition rates. The flooding of thawed permafrost areas creates anaerobic conditions favourable for decomposition by methanogenesis. Increased temperature is directly linked to increased soil respiration, and a global average temperature increase of 2°C is predicted to increase soil carbon release by 10 Pg, mainly owing to increase in microbial activity. Different microbial groups have distinct optimal temperature ranges for growth and activity. Increased temperature can affect the composition of the microbial community, which in some cases could reduce the release of soil organic carbon owing to the loss of acclimatized microbial groups (Li & Dickie 1987).

Tropical soils show higher emission rates of CO_2 as compared to the soils of temperate regions because of higher and longer thermal regimes, where rate of organic matter decomposition is much higher due to enhancement of microbial activities. An increase in temperature in a high-latitude ecosystem resulted in an up to 50% decrease in bacterial and fungal abundance and soil respiration, suggesting that increased temperature does not always lead to enhanced carbon loss to the atmosphere. In general, a rise in atmospheric temperature corresponds to a rise in microbial activity. Changing soil temperature will likely alter microbial mediated nitrification and denitrification dynamics in soil environment due to shift of nitrifiers and denitrifiers population. Sometimes perturbations in the soil environment could lead to community shifts and altered metabolic activity in microorganisms involved in soil nutrient cycling, and to increasing or decreasing survival and virulence of soil mediated pathogenic microorganisms like *Salmonella typhimurium*. Thus, microbial growth and activity generally decreases in winter, due to the decreased temperature. Extremely high temperatures, in general, are deleterious for many microorganisms. Indeed, some species may survive such adverse conditions by entering into inactive forms, which may resist high temperatures. However, such expected seasonal dynamics may change in specific soil ecosystems, for example, in tundra soils, microbial biomass is at its maximum in late winter time when temperature is low (Schadt et al. 2003). The optimum average temperature for survival of microbes is just above 20°C while the higher limit is around 50°C (Vannier 1994).

Impact of altered precipitation on microbial community: Another key determinant of the terrestrial microbial community structure and the decomposition rate of soil organic carbon is soil moisture, which can be affected by the 20% increase or decrease in precipitation rate that has been predicted by the Intergovernmental Panel on Climate Change (IPCC). Increasing the time between rainfall events, reduce soil microbial respiration (C-output) in a temperate tall grass prairie system, but simultaneously, increased carbon inputs via leaf photosynthesis resulting in net C uptake and storage (Fay et al. 2008). Long periods of drier conditions may limit microbial growth and decomposition and may consequently have a negative-feedback effect on carbon fluxes in some ecosystems. In wetlands and peat lands, soil drying may increase oxygen availability and enhance carbon cycling, thereby having a positive-feedback effect on CO_2 fluxes.
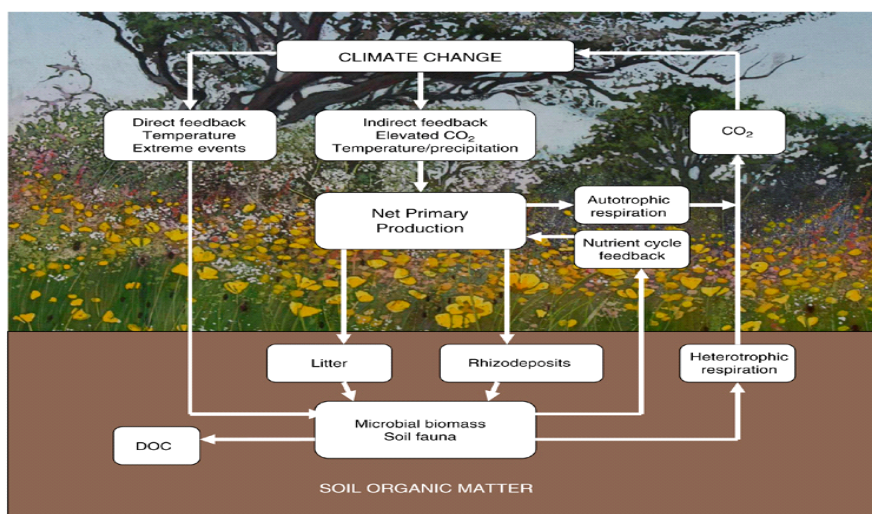
Fig.1: Direct and indirect impact of climate change on microbial community.

Periodic wetting and drying of soil also influence CO_2 evolution. When the soil is rewetted, the activity of microbes, which are found in the latent state in the dry soils, increases. This contributes to an increase in CO_2 evolution on rewetting of soil. Soil moisture can have both direct and indirect impacts on chemical engineers. Soil moisture directly influences the physiological status of bacteria (Harris 1980) and may limit their capacity to decompose various types of organic compounds. The soil moisture values for an optimal microbial activity vary depending on the basis of soil type and microbial community composition (Prado 1999). Soil moisture also indirectly influences microbial community growth, activity and composition through the modification of the quality and the quantity of plant litter production. These can affect plant-microbes interactions. Water availability and temperature are key drivers of N mineralization, denitrification and microbial activity in dry land soils (Gallardo & Schlesinger 1992, Gallardo & Merino 1998), and hence, climate change will exert significant impacts on these processes through their effects on soil temperature and water availability (Robertson & Groffman 2007, Schlesinger & Bernhardt 2013).

Impact of increased CO2 on microbial community: The present atmospheric CO_2 increase is caused by anthropogenic emissions of CO_2. Table 1 shows that the atmospheric CO_2 levels are increasing at a rate of 0.4% per year and are predicted to double by 2100 largely as a result of human activities such as fossil fuel, combustion and land-use changes.

An estimated 30-40% of the CO_2 released by humans into the atmosphere dissolves into oceans, rivers and lakes (Feely et al. 2004, Millero 1995), which contributes to ocean acidification. The direct effect of elevated CO_2 in stimulating above-ground biomass production has been extensively studied (Pan et al. 1998). This increase in above-ground net primary production (ANPP) has been shown to increase C supply below-ground and stimulates soil biological activity (Pendall et al. 2004). High CO_2 concentrations accelerate average growth rate of plants, thereby allowing them to sequester more CO_2. This growth of plants was coupled with an increase in soil respiration due to the increase in nutrients available for decomposition by releasing more CO_2 into the atmosphere. Increased levels of CO_2 quantitatively and qualitatively alter the release of labile sugars, organic acids and amino acids from plant roots, and this can stimulate microbial growth and activity. In the long term, it is argued that the increase in microbial biomass as a result of increased carbon release by the roots can lead to immobilization of soil N, thereby limiting the nitrogen available for plants and creating a negative feedback that constraints future increases in plant growth. This, in turn, may lead to an increased soil carbon to nitrogen ratio, which favours higher fungal dominance and diversity. Global carbon flux between the atmosphere and terrestrial ecosystems is depicted in Fig. 2

Fungi generally have higher carbon assimilation efficiencies (they store more C than they metabolize) than bacteria, and fungal cell walls mainly consist of carbon polymers (chitin and melatin) that are much more resistant to decomposition than those in bacterial cell membranes and walls (phospholipids and peptidoglycan). As a result, in ecosystems dominated by fungi, soil respiration rates are typically low, which increases the potential for carbon sequestration. An increase in atmospheric CO_2 may be one of the effects of climate change, can significantly change soil en-

Table1: Year-wise data for global carbon emissions (fossil fuels, combustion and land-use change).

S.No.	Year	CO_2 concentration in atmosphere(ppm)	Remarks
1.	2014	398.55	Copenhagen Accord
2.	2013	396.48	
3.	2012	393.82	
4.	2011	391.63	
5.	2010	389.85	
6.	2009	387.37	
7.	2008	385.59	
8.	2007	383.76	
9.	2006	381.90	
10.	1997	356.38	Kyoto Protocol
11.	1992	356.38	Earth Summit in Rio de Janeiro
12.	1987	349.16	The last year when the annual CO_2 level was less than 350 ppm
13.	1959	315.97	The first year with a full year of instrument data

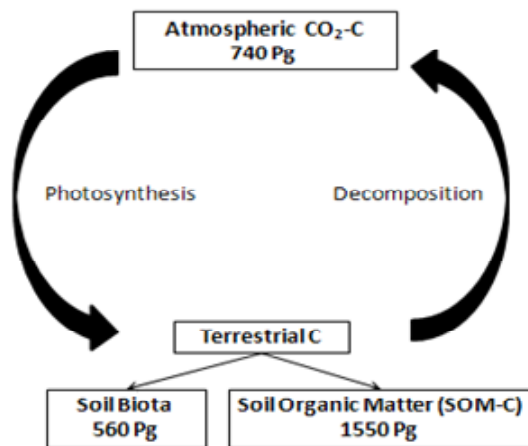*Source*: Annual CO_2 Data: NOAA-ESRl data file created (2015).

Fig. 2: Conceptual diagram of global carbon flux between the atmosphere and terrestrial ecosystems. Transformation of carbon flux from terrestrial to atmospheric C pools by decomposition includes the breakdown of plant residue, litter, and soil organic matter by soil organisms, which is balanced by the net assimilation of carbon via photosynthesis in ecosystems that are in steady state (Wolf & Wagner 2005, Lal 2008). All units are in Pg C (10^{15}g).

vironment mainly by modifying the distribution of above and below-ground nutrients. For example, an increase of atmospheric CO_2 could lead to an increased plant growth, since CO_2 is the molecular building block for photosynthesis. This may lead to an increase in litter production rate and a modification in litter chemical composition, which may in turn lead to a change in its digestibility. Such modifications will then influence the nature of organic matter available for soil microorganisms (Zak et al. 2000). As a consequence, a modified litter production may modify the overall carbon supply and the N flow between plants and microorganisms (Berntson & Bazzaz 1997). In addition, elevated CO_2 may lead to an increased root growth which will have a significant impact on soil structure and major consequences for soil biota.

Impact of drought condition on microbial community: As a result of increased temperatures, a concomitant increase in the frequency and duration of drought events in mesic ecosystems is anticipated (Knapp et al. 2008). The expected exposure to water stress is likely to affect both microbial and plant communities by interrupting key nutrient cycles and plant-microbe feedbacks. Drought condition, significantly reduced soil moisture, thereby creating unfavourable growth conditions that led to a 50-80% reduction in the microbial population size (Sheik 2011). Both establishment and activity of the legume *Rhizobium* symbiosis have been found to be sensitive to drought stress (Kirda et al. 1989, Sprent 1971). Pena-Cabriales & Alexander (1979) reported a biphasic decline in *Rhizobium japonicum* and *Rhizobium leguminosarum* numbers in soils undergoing drying.

MITIGATION STRATEGIES

To a large extent, the same practices that increase productivity and resilience to climate change also provide positive co-benefits with respect to agricultural mitigation of GHGs. There are three main mechanisms for mitigating GHGs in agriculture: a) reducing emissions, b) enhancing removal of carbon from the atmosphere and c) avoiding emissions through the use of bioenergy or agricultural intensification rather than expansion (Smith et al. 2007). There is a positive correlation between soil organic carbon and crop yield, practices that increase soil fertility and crop productivity also mitigate GHGs emissions, particularly in areas where soil degradation is a major challenge (Lal 2004). There is little research to date on the synergies and tradeoffs between agricultural adaptation, mitigation and productivity impacts. FAO (2009) differentiates between activities with high versus low mitigation potential and those with

Fig. 3: Mitigation potential and food security prospects of selected activities.

Mitigation Potential			
High	• Second generation biofuels • Conservation tillage/residue management (when tradeoffs with livestock feed)	• Integrated soil fertility Management • Improved seed • Low-energy irrigation • Conservation tillage/residue management • Improved fallow	
Low	• Overgrazing • Soil nutrient mining • Bare fallow	• Mechanized farming • Ground water pumping	
	Low	**High**	

rce: Adapted from FAO (2009).

high versus low food security prospects (Fig. 3).

Mulching/light soil sealing: Mulching consists of covering the soil surface to protect against erosion and to enhance its fertility. Mulch is usually applied towards the beginning of the crop growing season, and may be reapplied as necessary. It serves initially to warm the soil through retaining heat and moisture. A variety of materials can be used as mulch including organic residues (e.g. crop residue, hay, bark), manures, sewage sludge, compost and rubber or plastic films.

Application of organic residues (compost/manure/sludge): Application of animal manure, sludge or other carbon-rich wastes, such as coffee-berry pulp, cereals and legumes straw or compost improves the organic matter content of the soil. For agricultural purpose it is usually better to allow decomposition of organic residues for a period before applying them to the field. This is because addition of carbon-rich compounds immobilises available N in the soil temporarily as micro-organisms need both C and N for their growth and development.

Fertilizers: High levels of some inorganic nitrogenous fertilizers provide microbes nitrogen with easy to use, thereby boosting their activity. This increases the rate of decomposition of low quality organic inputs and soil organic matter, resulting in less of soil carbon and the continuing decline of soil organic matter content which, ultimately, results in loss of soil structure and water holding capacity.

Crop management

Selection of the crop species: The choice of the cultivated crop is important as it defines the kind of habitat available to soil fauna. For example, legumes can act as natural fertilisers, improving the N concentration in soil by establishing symbiotic relationship with rhizobia. Application of nitrate fertilizers as calcium ammonium nitrate in crops with aerobic conditions and ammonium fertilizers as ammonium sulphate, urea, in wetland crops also helping reducing the nitrous oxide (N_2O) emission (Pathak & Nedwell 2001).

Crop rotations: Crop rotations can also help to avoid the build up of pathogens and pests, as the alteration of crops modifies the associated communities of biological regulators. Appropriate crop management practices, which lead to increase N use efficiency and yield, hold the key to reduce nitrous oxide emission.

Landscape management

Hedgerows and grassy field margins: Establishing hedgerows or grassy strips at the edge of arable fields offer a stable habitat, food and a protective environment for soil fauna next to the intensively managed fields. Hedgerows are even more favourable to soil organisms, in particular biological regulators, than grassy field margins, however, due to their low mobility; the soil organisms will have only limited dispersal into the fields. That also counts for field margins, in which 10% of the soil dwelling species present in farmland were found to occur exclusively.

Microbial communities and mitigation options

Managing microbial communities to reduce carbon dioxide emissions: Currently, soils contain about 2,000 Pg of organic carbon, which is twice the amount of carbon in the atmosphere and three times the quantity found in vegetation (IPCC 2007, Smith 2004). The capacity of different land types (for example, woodland, pasture and arable land) to store carbon differs, and it has been suggested that land use can be managed to sequester a further 1 Pg of carbon per year in soils (Smith 2004, Houghton 2008), this potential has received considerable scientific attention (Lal 2008, Busse 2009).

Managing microbial communities to reduce methane emissions: Global emissions of CH_4 are arguably even more directly controlled by microorganisms than emissions of CO_2. Natural emissions (~250 million tonnes CH_4 per year) are dominated by microbial methanogenesis, a process that is carried out by a group of anaerobic archaea in wetlands, oceans, rumens and termite guts. However, these natural sources are exceeded by emissions from human activities (mainly rice cultivation, land fill, fossil fuel extraction and livestock farming). Methanotrophic bacteria serve as a crucial buffer to the huge amounts of CH_4 produced in some of these environments. The so-called 'low-affinity' methanotrophs (active only at a CH_4 concentration of >40 ppm; also called type I methanotrophs), which mainly belong to the class Gammaproteo bacteria, can often consume a large proportion of the CH_4 produced in soils before it escapes to the atmosphere.

CONCLUSION

Lastly, it is concluded that the climate change, as noticed

through trends of temperature rise, altered precipitation and increased CO_2 concentration, is a major concern to microbial community. Increase in temperature over a long period of time will not affect the microbial population a lot as it will get adapted to it, but it will contribute to increase in CO_2 emission which is a major greenhouse gas. Microbes have emerged as the major contributor as well as consumer for GHGs as the microorganisms are the main intermediaries of C turnover in soil. Climate change is likely to have significant impacts on soils that may affect all of the services provided by soil microbial community; indeed the quantification of these impacts is needed. In any case, all mitigation and attenuation measures taken to limit global climate change are expected to have a beneficial impact on soil microbial community preservation, soil functioning and associated services.

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