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# Impacts of Climate Change on Soil Microbial Diversity, Distribution and Abundance: A Systematic Review

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## Abstract

Climate change, driven by anthropogenic activities, has far-reaching consequences for our planet. Among its many impacts, changes in temperature, elevated carbon dioxide levels, and shifts in greenhouse gas concentrations significantly affect soil ecosystems. In particular, soil microbial communities play a pivotal role in nutrient cycling, organic matter decomposition, and overall soil health. Soil microbial communities respond differently to effects of climate change like elevated warming and precipitation. The change in climatic condition is reported for adversely affecting soil biological activity directly through either drying or wetting of soil or affecting their associated plants. This review delves into the intricate relationship between climate change and soil microbial abundance diversity and distribution. The paper also discusses climatic change pressure on soil enzymatic activity and microbial biomasses as well as soil faunal activity as they are key indicators of soil health in changing climate. Soil microbial community cope with climate through changing their diversity and physiological characteristics and through changing their symbiotic plants, which indicate role of soil microbes in withstanding negative impact of climate change.

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Climate change, temperature, Mycorrhizae, soil microbial, bacteria.

## Introduction

Any change in the climate over time, whether brought on by human activity or natural variability, is considered climate change, according to the Inter governmental Panel on Climatic Change (IPCC) (IPCC, 2007). The primary environmental issue of our day is the potential for global climate change, which is brought on by human alteration of the atmosphere (Anonymous, 2007). The atmospheric concentration of $CO_2$ has increased by around 25% due to the combination of deforestation and the use of fossil fuels (Chakravarty *et al.,* 2012). Over the last century, rising greenhouse gas emissions have caused a 0.74°C increase in global warming; eleven of the twelve warmest years on record have occurred between 1995 and 2006 (IPCC, 2007). According to IPCC predictions, temperatures will rise by 1.8–4.0°C by the end of this century (Anonymous, 2007). The issues of climate change due to this warming have led to a serious concern of agricultural productivity worldwide, because agriculture is both a possible contributor of GHGs to the atmosphere and an industry that is highly sensitive to climatic variates.

Global warming and climate change are often interchangeably used and understood, but these terms are not identical. Climate change includes both warming and cooling conditions, while global warming pertains only to climatic changes related to increase in temperatures (Grover, 2004). The climatic 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 atmospheric component of the climatic system most obviously characterizes climate. It is often defined as 'average weather'. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time ranging from months to millions of years (Anonymous, 2007).

The global warming caused by an increased concentration of greenhouse gases in the atmosphere is one of the most serious environmental problems facing the world today. In addition to global warming, increased greenhouse gas concentrations may increase the occurrence of precipitation extremes greater precipitation is expected in already-wet areas and increased drought in already-dry areas (Singh *et al.,* 2011). Furthermore, widespread expansion of industry and agricultural activities may increase atmospheric nitrogen deposition to unprecedented levels, which will modify climate change impacts. Climate change is also expected to increase the severity and frequency of wildfire, floods, and pest and pathogen attacks. These global environmental changes will pose serious consequences for the overall functioning of terrestrial ecosystems, particularly for agriculture and forestry. 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 the case for atmospheric $CO_2$ concentrations that increase continuously. Additionally, global surface temperatures are predicted to increase between 1.8 and 3.6 1C by the year 2100, driven by increased atmospheric $CO_2$ levels derived from natural and/or anthropogenic sources (IPCC, 2007). Because of increased temperature, soil water content is expected to decrease in some areas leading to enhanced drought in several areas of the world. Therefore, considerable climate changes are currently ongoing. These climate-changing parameters are known to affect terrestrial macro organisms such as plants. However, recent studies have shown that other organisms and ecosystems may be impacted as well. Virtually all land plant taxa investigated have well-established symbioses with a large variety of microorganisms (Brundrett, 2009). Many of these plant growth-promoting microorganisms colonize the rhizosphere, the portion of soil attached to the root surface and influenced by root exudates and by microorganisms (Bent, 2006).

Even though major impact of climate change on plant and animals was discussed well microbial aspects of this universal problem remain underestimated. But recently different researchers tried to dig out the impact of climate change on terrestrial and marine microorganisms. This review was aimed to review major climatic factors and their effect on abundance, diversity and distribution of soil microbial as well as mechanism undertaken by microorganisms to overcome climatic changes exerted on them.

## Climatic factors affecting the microbial diversity, distribution and abundance

### Effects of temperature

Microbial communities have to adapt to the warming climate or perish. Numerous investigations have demonstrated an increase in microbial biomass in short-term tests; nevertheless, biomass is more likely to decline in the long run at elevated temperatures. This is due to the fact that at higher temperatures, microbial growth efficiency varies (Schimel *et al.,* 2007). One example is that increasing temperatures change the permeability and fluidity of cell membranes, necessitating the resynthesis of membrane lipids. One way carbon can be used for energy instead of biomass is through the high energetic cost of this stress reaction. Biomass cannot be sustained at higher temperatures and may even decrease if the microbial energy demand beyond the limit of labile carbon stores (Balser and Firestone, 2005). Increased temperature, however, will cause a shift in carbon allocation from growth to acclimation with a corresponding drop in growth efficiency (i.e., an increase in respiration per unit biomass) if the microbial community can get the required labile carbon (Schimel *et al.,* 2007). Microbial biomass might even increase in this situation as opposed to decreasing. The results of climatic treatments (raised temperature or precipitation) on microbial biomass or community structure were generally not very significant, with responses to elevated temperature being larger than those to elevated precipitation. A microbial reaction to high temperatures was described by Gutknecht (2007), and it resembled the result of adding nitrogen. The relative abundance of various bacterial and general fungal microbial markers increased, while mycorrhizal abundance declined. Elevated temperatures have the potential to positively or negatively affect arbuscular mycorrhizal (AM) colonization and development, as suggested by Fitter *et al.,* (2000). Given the significant role mycorrhizas play in plant nutrition and the reactions of plants, communities, and ecosystems to global change, these variations in mycorrhizal fungal biomass may be significant. While slower-growing microbes like fungus and actinomycetes were unaffected, the initial rise in microbial biomass was probably caused by fast-growing bacteria that first reacted to the rising temperature. Similar to this, whereas fungi and biomarkers may decrease at higher temperatures, the relative abundance of Gram-positive and gram-negative bacteria may increase with temperature, possibly as a result of a change in the substrates that are available (Zogg *et al.,* 1997). Collectively, these findings highlight the significance of comprehending the various ways in which microorganisms react to high temperatures and the ways in which these diverse reactions influence the duration and timing of the community's overall response to high temperatures or maybe other global changes.

Numerous elements, such as terrain, vegetation type, temperature, parent material, soil age and texture, and soil community makeup, affect a soil's capacity to store carbon. Ultimately, nevertheless, microbial decomposers govern the rate-limiting phases in the decomposition process, which in turn limits the impact of abiotic variables on decomposition (Classen *et al.,* 2015). Warming modifies the physiology of decomposers, influencing the soil's $CO_2$ output.

Elevated temperatures have the potential to hasten the decomposition process of fungi, leading to a rise in carbon dioxide emissions from the soil. Higher temperatures do, however, also result in higher soil nitrogen levels, which slow down the rate at which fungi decompose. In actuality, microbial diversity and activity are adversely impacted by increased nitrogen availability (American Society for Microbiology, 2008). Conversely, bacterial metabolic responses are less efficient when they are stressed by a warmer climate. Because of this, these bacteria release more carbon dioxide rather than converting a large amount of carbon to biomass (Zimmer, 2010). Nitrous oxide and methane are released by plants as a result of their absorption of high quantities of carbon dioxide created in this and other ways. The decomposers' temperature sensitivity, the availability of substrate, interactions with above-ground processes, and environmental factors like soil moisture and possible physiological adaptations all influence the overall microbial response to warming in terms of soil organic matter decomposition (Schindlbacher *et al.,* 2011). It is important to note that various soils respond differently to increased temperatures when it comes to the release of carbon dioxide as a result of decomposition. The microbial community inhibited the effects of temperature variation on carbon dioxide release in managed agricultural soils. Nevertheless, the areas that are warming the fastest are the arctic and boreal soils, where there is the most stimulation. Because microbial biomass is more resistant to decay than recalcitrant plant matter, carbon utilization efficiency is a critical factor in determining the long-term stability of carbon in soil (Schurig *et al.,* 2013).

## Global warming/Greenhouse Gases

The emissions of Greenhouse Gases (GHGs), such as methane ($CH_{4)}$, carbon dioxide ($CO_{2)}$, and nitrous oxide ($N_2O$), are a natural phenomenon that has been recognized to contribute to more than 90% of the anthropogenic climate warming. Atmospheric concentrations of these gases have exceeded the pre-industrial levels by 40%, 150%, and 20%, respectively. Additionally, they have already raised the global average surface temperature by 0.39 $^0$C between 1901 and 2012 (IPCC, 2013). Although many studies consider $CO_2$ to be the most important greenhouse gas, $CH_4$ and $N_2O$ also play major roles in terrestrial ecosystems (Li *et al.,* 2015). Forest soils have been identified to be a significant sink for atmospheric $CH_4$, and it is estimated that $CH_4$ uptake activities of soils represent 3%–9% of the global atmospheric $CH_4$ sinks. It has also been identified as a significant source for N trace gases, accounting for 60% of the total annual $N_2O$ emissions. Additionally, with a span of 100 years, the global warming potential of $CH_4$ and $N_2O$ is 28 and 265 times that of $CO_2$, respectively (IPCC, 2013).

Significant volumes of greenhouse gases (GHGs), namely $CO_2$, $CH_4$, and $N_2O$, are released into the atmosphere by agriculture (Anonymous, 2007). $N_2O$ is released from the microbial transformation of nitrogen in soils and manures, especially under wet conditions where available nitrogen exceeds plant requirements (Oenema *et al.,* 2005); $CO_2$ is released from microbial decay or burning plant litter and soil organic matter and $CH_4$ is released from fermentative digestion by ruminants, stored manures, paddy cultivation, or decomposition of organic materials in anaerobic conditions (Smith, 2004). Between 1990 and 2005, agricultural emissions of $CH_4$ and $N_2O$ grew by over 17% globally. Together, these three sources—soil $N_2O$ emissions, enteric fermentation ($CH_4$), and biomass burning ($N_2O$ and $CH_4$)—accounted for 88% of the increase. Livestock (cattle and sheep) account for about one-third of global anthropogenic emission of $CH_4$. Agricultural lands generate very large

$CO_2$ fluxes both to and from the atmosphere but the net flux is small, less than 1% of global anthropogenic $CO_2$ emissions. GHG emissions from deforestation mainly in tropical countries contributed additional $CO_2$ thus equaling or exceeding emissions from all other agricultural sources combined (Smith *et al.,* 2007).

Until 2030, there will be a 35–60% increase in $N_2O$ emissions as a result of the growing use of nitrogenous fertilizer and the generation of animal manure. The yearly emissions of greenhouse gases from agriculture may rise even more if food demands rise and dietary patterns change as anticipated (Smith *et al.,* 2007). According to projections, enteric fermentation and manure management will raise $CH_4$ emissions by 21% between 2005 and 2020, whereas $CH_4$ emissions will climb by 60% until 2030 if cattle numbers expand correspondingly (Anonymous, 2007). The main sources of greenhouse gases (GHG) in agriculture are related to the global cycles of carbon and nitrogen (N). GHG, such as carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), troposphere ozone ($O_3$) and chlorofluorocarbons (CFCs), cause the atmosphere and oceans to warm up (IPCC, 2007). Since the Industrial Revolution, GHG emissions have risen sharply due to the use of fossil fuels and the change of land use for industrial and transportation purposes. The IPCC reported that the $CO_2$ concentration in the atmosphere increased from about 280 ppm before industrialization to 379 ppm in 2005, surpassing the natural variation of the last 650 000 years (180 to 300 ppm, as measured from ice cores). Human activities that generate GHG emissions include land use and land use change in agricultural and forest systems, industrial development, and urban expansion, among others. These activities have altered the C and N cycles in terrestrial ecosystems (IPCC, 2007). The amount of $CO_2$, $N_2O$ and $CH_4$ emissions from agricultural soils depends on the biophysical processes and the input and breakdown of organic matter in the soil. $CO_2$is produced under aerobic soil conditions, while $CH_4$ is produced under anaerobic soil conditions and $N_2O$ is produced by nitrification and denitrification of mineral-N. Elevated atmospheric levels of carbon dioxide cause soil microbes to emit more potent greenhouse gases such as methane and nitrous oxide. In fact, higher $CO_2$ levels not only increase $CH_4$ efflux but also decrease the uptake of methane by soil microorganisms (Phillips *et al.,* 2001). Moreover, higher levels of carbon dioxide also lead to distinct and important alterations in the microbial communities of trees leaves and leaves that decompose in streams. This could have widespread consequences on the food chain; as such, microorganisms are a source of nutrients for the small phytophagous animals (American Society for Microbiology, 2008). In addition, increase in microbial respiration takes place due to accelerated plant productivity that occurs due to elevated $CO_2$, which in turn provides more carbon substrate to soil microorganisms (De Graaff *et al.,* 2006).

## Effects of changes in precipitation and soil moisture

Climate change increases the risk of both drought and flooding. It also causes a shift in the timing of snowmelt. This is highly relevant because fluxes caused by rainfall play a key role in determining whether ecosystems serve as $CO_2$ sinks or sources for the atmosphere (Shim *et al.,* 2009). Rainfall actually plays a major role in influencing how variable soil moisture and respiration activity are (Aanderud *et al.,* 2011). Changes in precipitation regimes are important because the amount of moisture determines the nature of terrestrial microbial communities and the rate of soil decomposition, which can vary by 20%. According to Singh *et al.,* (2010), soil drying enhances oxygen availability and promotes carbon cycling in wetlands and peatlands, which raises $CO_2$ flux. Changes in precipitation regimes have the strongest effects on community composition among the many aspects of climate change and its aftereffects that modify the total abundance of bacteria and fungi (Castro *et al.,* 2010). Changes in precipitation and soil moisture levels can cause changes in the ratio of bacteria to fungus and in the composition of their communities, depending on the factors limiting the productivity of the ecosystem. In actuality, while bacterial communities persist, minute variations in soil moisture (less than a 30% decrease in water-holding capacity) can alter the species dominance in soil fungal communities (Classen *et al.,* 2015). The winter season conditions have an impact on the make-up and activity of soil microbial communities, which in turn has an impact on how sensitive soil respiration is to temperature and moisture. As a result, these circumstances affect the flow of carbon dioxide ($CO_2$) out of soils. Winter soil respiration can be significantly impacted by snowfall's impacts on microbial communities and their metabolic activity (Aanderud *et al.,* 2013). Indeed, wintertime respiration dynamics can be significantly impacted by snow-mediated modifications to the structure of microbial communities. Several terrestrial ecosystems are expected to experience varying amounts of snowfall as a result of climate change (Aanderud *et al.,* 2013). This could have significant effects since the depth of the snowpack plays a crucial role in controlling the temperature and moisture levels, which in turn control the respiration of the winter soil. Heterotrophic respiration may be enhanced by thick snowpack's ability to shield soils from lower air temperatures (Rey *et al.,* 2002). It is important to note that microbial activity under snow in coniferous woods is susceptible to temperature increases brought on by climate change. Due to the snowpack's exceptionally low temperature, which is essential for the growth of snow molds, this activity is particularly prevalent in late winter. About 10–30% of the total yearly carbon dioxide output in these regions is attributed to these molds.

The late winter season, which is marked by below-freezing temperatures, is probably going to get shorter as temperatures rise. It would therefore result in lower carbon dioxide emissions from the snow molds. However, as trees rely on water from snowmelt, this would have a detrimental effect on their mortality rate, which would ultimately result in a reduction in carbon fixation as a whole (American Society for Microbiology, 2008). The moisture that is available to organisms is influenced by soil water, which also has an impact on the osmotic pressure, pH, soluble material content, soil aeration status, and other factors.

It makes logical sense, and it has been demonstrated that the amount of water in the soil will decrease with warmth. It is difficult to provide an empirical description of the link, though. An equation characterizing the relationship between soil respiration and moisture or between moisture and temperature is not universally accepted (Lavigne *et al.,* 2004; Maurer and Bowling, 2014). The ambiguity around temperature links may be attributed, as with other elements, in large part to interactions. In contrast to temperature change, water change occurs on various time and spatial scales. Drought, flooding, wet-dry cycles, and other minor variations can all be signs of moisture changes. The innate regime of a community influences these many changes, which have varying effects on the structural and functional aspects of the community. There are several mechanisms or physical processes affecting microbial communities that vary with moisture content (Schimel, 2018). Precipitation is generally agreed to constrain decomposition at its extremes of dry (water stress) and wet (anoxia). Although a general interaction between oxygen concentrations and soil moisture is intuitively obvious, soil moisture effects are not limited to anoxia (Schjonning *et al.,* 2003).

One important component of global change is water. Large carbon sinks are found in wetter soils like peats and wetlands. In general, heterotrophic respiration is thought to be adversely correlated with water content above the soil moisture optimal range, which is usually expressed as 60–80% of the water-holding capacity. So effective are wet soils at erecting chemical and physical barriers to aerobic respiration that saturating soils may be a future method for managing carbon sequestration. Anaerobic wetland conditions may be less of a carbon sink with global climate change, according to additional data that takes into account the interacting component of increasing carbon dioxide. As perilous as asserting a universal temperature optimum, generalizing moisture response data can be caused by the adaptation of a microbial population to a particular precipitation regime. Fierer *et al.,* (2003) provide an example of community adaptation and process response to moisture levels. Drying-wetting regimes were found to significantly impact on bacterial community composition in oak woodland soils, which are less frequently exposed to moisture stress, but not in grassland soils. Size and function of litter decomposers can also be strongly affected by their moisture stress history.

Drought, irrigation, flooding, and re-wetting or other pulse events all can be expected to have different responses compared with modest water stress or modest increases in soil moisture (Schimel *et al.,* 2007). Microbial activity or biomass may increase during wet seasons or after 'wet-up' (the period when soils regain moisture after the dry season (Fierer *et al.,* 2003). Rewetting after drying also has unique process implications, and several studies address it. For example, dissolved organic carbon release is enhanced when dry soils are rewetted but these effects may be community-specific (Reichstein *et al.,* 2005). Microbial activity may also change when soil moisture levels rise. Nonetheless, it is possible that soil moisture affects things even at lower levels in specific situations. It is evident that the impact of moisture is physically and biologically complicated when one takes into account the significance of soil microsites, water films, osmotic stress tolerances, ion concentrations, and the differential water retention of different pore sizes. Carbon dioxide efflux rates can be affected by non-equilibrium environmental circumstances, such as minor moisture variations that restrict or hasten the diffusion of carbon dioxide from soils or the surface layer. Moderate drying has been found to have a major impact on decomposition. Soil respiration can decrease by 25–50% even under mild water stress. (Lavigne *et al.,* 2004).

Large pulses in nutrient mineralization and soil respiration can result from drying and rewetting the soil.

In dry and semiarid habitats, where the majority of the growing season rainfall occurs as intermittent occurrences, respiration pulses after rainfall may make up the majority of the total annual heterotrophic respiration. In the Mediterranean and more mesic climates (Carbone *et al.,* 2011), where a single rainfall event may release as much as 10% of the yearly net ecosystem exchange, there is also significant fluctuation in respiration. Most microbial species have reduced metabolic activity when soil water potential falls, which lowers respiration and nutrient mineralization (Schimel *et al.,* 2007). Drying the soil also decreases the mobility of solutes and enzymes, which in turn lowers the availability of substrate for the decomposers. Rewetting subsequently sets off a series of events that lead to increased respiration and nutritional mineralization. These reactions include the mobilization of C that is physically protected in aggregates, the release of intracellular osmolites, and the enhancement of metabolic and enzymatic activity (Schimel *et al.,* 2007). Both physiological reactions to water stress and diffusive constraints are involved in these processes, and they are closely related to the dynamics of soil water (Bauer *et al.,* 2008). Because the soil's water-filled pores shrink as it dries, solute and water diffusivity, as well as microbial motility, decline. According to Schjonning *et al.,* (2003), access to substrates presents a barrier to microbial activity in dry soils that cannot be overcome by solely physiological adaptation.

## Effects of climate change on soil microbial diversity, distribution and abundance

### Changes in soil microbial diversity and abundance

### Soil Bacteria

The biogeochemical cycling of carbon and nitrogen as well as the mineralization of organic matter are two processes in which soil bacteria are crucial. Properties of the soil can affect the community of bacteria in the soil (Burton *et al.,* 2010). Soil bacterial populations are also modified by seasonal variations in temperature and precipitation. Zhou *et al.,* (2016) found that the complicated responses of soil bacterial composition and diversity across altitudinal gradients were caused by a number of variables, including temperature. Research has also suggested that precipitation may have an indirect impact on bacterial communities by altering soil moisture, which could account for compositional variations amongst perhumid forest sites at comparable elevations but with varying precipitation (Lin *et al.,* 2014). Soil pH may play a role in creating biogeographical patterns and explaining spatial differences in bacterial community structures. Elevation diversity gradients of soil bacteria are regulated by the indirect impacts of climate conditions, which are mediated through plant functional diversity and soil characteristics (Shigyo *et al.,* 2019). Because of the physiological reactions of microbes to climate circumstances, climate conditions, in particular soil temperature and soil water content, can be important determinants controlling the seasonal dynamics of microbial communities in soils (Baldrian *et al.,* 2013).

### Arbuscular Micro Fungi (AMF)

Most terrestrial plants have roots colonized by arbuscular mycorrhizal fungi (AMF), which are plant symbionts that provide improved water and nutrient uptake, higher resilience to drought and disease, and increased plant productivity in return for carbon (C) (Smith and Read, 2008). AMF are thought to represent a crucial link between above- and below-ground processes and are a significant contribution to the terrestrial C and nutrient cycles (Fitter *et al.,* 2000). It is not surprising that recent research has found that AMF may be a key mediator of plant and ecological responses to climate change, given their extensive significance. Most research has found that temperature and/or experimentally raised $CO_2$ levels cause AMF colonization to increase (Compant *et al.,* 2010). Research on how AMF and their plant hosts react to climate change is still needed because AMF have been shown to have a far higher species variety than previously thought (Kivlin *et al.,* 2011), and the advantages of AMF symbioses vary throughout plants. Several factors could affect the way AMF reacts to climate change. It is possible that higher plant productivity, which raises the need for plant nutrients and increases the generation of root exudates, is the cause of the overall positive response of AMF colonization to rising CO2 levels and warmth (Fitter *et al.,* 2000). Many places are concerned about the increasing severity of droughts, and studies have shown that AMF can improve water interactions and increase resistance to drought. However, a number of studies have found that increased drought can have a negative effect on AMF, depending on the species of AMF (Davies *et al.,* 2002), hyphal growth within or outside the roots, or the species of plant. In a long-term climate manipulation study, Staddon *et al.,* (2003) found that increased AMF colonization in response to heat was mediated by soil moisture. Furthermore, they speculated that the effect of soil moisture could have been further mediated by changes in plant diversity and cover of various species, which were also highly correlated with mycorrhizal measures. It is well established that a decrease in soil nutrient levels, especially of phosphorus (P) and nitrogen (N), can result in an increase in AMF colonization, whereas excess nutrients can result in lower colonization (Rillig *et al.,* 2002). Important factors such as soil characteristics and plant community composition often have high local variability. The effect of elevated $CO_2$ on plant growth has been studied in detail, and current evidence suggests that impacts on AM fungi are likely to be indirect responses, mediated via changes in plant growth (Staddon *et al.,* 2003).

## Change in Soil Fauna

Changes in climate might affect soil biology because both direct and indirect effects on soil biology may arise from the various environmental changes brought on by climate change. According to Lavelle *et al.,* (1997), soil organisms, especially the "soil engineers"—termites and earthworms—can have a significant impact on the physical properties of soil, including hydraulic conductivity. Because there are no mixing activities when these macro-engineers are absent, there is a high profile differential (Lavelle *et al.,* 1997). There have been reports on the significant role earthworm burrows, or macropores, play in regulating the hydraulic qualities of soil. According to Chan (2004), there were 157/$m^2$ of these burrows in the soil beneath pastures, and the infiltration rate of a single anecic earthworm burrow was comparable to 1.9 times that via the remaining soil matrix over a 1 $m^2$ area. Therefore, a decrease in the number of these transmitting macropores caused by the loss or reduction of earthworms could have a significant impact on the hydrology of the soils. Increased runoff and soil erosion in the nearby cropping soils were caused by the loss of continuous earthworm routes (Chan, 2004). The occupants of the soil may directly respond to climate change by altering their activity, composition, abundance, and migration patterns. It is projected that the activity and survival of soil organisms would be differently affected by the anticipated changes in the water regime brought on by climate change, which will result in longer summer droughts and an increase in the frequency of extreme events. Temperature increases may also directly affect the duration of the life cycles of soil organisms; these impacts are probably species-specific and may have an impact on the ecosystems' variety, abundance, and activity. Even tiny alterations in the environmental conditions of the soil can cause earthworms to undergo significant changes in their behavior and ability to survive. Food consumption for earthworms (*Lumbricus terrestris*) rose with temperature up to 20 °C but decreased at 22 °C, according to Daniel (1991) observations. When the soil water potential fell below 7kPa, food intake also decreased. Moreover, temperature affected the rate at which earthworms buried trash, which is a gauge of the rate of decomposition. A. longa cocoons rarely survived two months in soil that had been air-dried, (Baker and Whiby, 2003). According to Warburg *et al.,* (1984), soil organisms may migrate vertically within the profile in reaction to climate change, such as downward migration in response to soil dryness. According to Lavelle *et al.,* (1997), the anticipated temperature increases will favor endogeic earthworm species that eat soil as well as humivorous termites by expanding their latitudinal distribution. Changes in the amount and quality of litter, a food source, have an indirect impact on soil organisms as a result of climate change (Couteauz and Bolger, 2000). Large portions of the world, especially those that get rain-fed crops, are expected to encounter a fall in agricultural crop yields, which will reduce soil ecosystem cover and input. As stated earlier, both direct and indirect effects of climate change on soil biology have the potential to significantly alter the structure of the soil. The magnitude of climatic changes, the type of soil in the area, and the soil organisms will all affect how much the soil structures change. More observation and investigation will be necessary to gain a better understanding of the impact (Singh *et al.,* 2011).

## Change on Soil enzyme

Soil enzyme activity are being affected by both biotic (such as enzyme production and secretion) and abiotic (such as temperature, water potential, and pH) factors as a result of rising atmospheric concentrations of $CO_2$ and other greenhouse gases. Extreme weather events brought on by climate change are having an impact on agriculture, which may have an impact on the quantity and quality of soil enzymatic activity (Aamir *et al.,* 2019). The decomposition, nutrient cycling, and interactions between plants and microbes in the ecosystem will all be significantly impacted by these changes, which will ultimately have an impact on productivity and net carbon balance. Despite their great significance, the effects of climate change on microorganisms and their extracellular enzymes are not fully understood, however they can be anticipated, evaluated, and controlled (Burns *et al.,* 2013; Steinweg *et al.,* 2013). Growing interest in enhancing C sequestration through modeling, theory, and experimental study has been motivated by concerns about the possible effects of climate change on soil processes (Burns *et al.,* 2013). Soil organic matter (SOM) is synthesized and decomposed by microbial enzyme activities; however, the pace at which these processes occur affects the soil's net carbon balance. High $CO_2$ levels in the atmosphere can have both direct and indirect effects on soil microbial populations. Microbial activity are substantially influenced by increased plant rhizode position, efficient use of water, and rapid uptake of nutrients under elevated atmospheric $CO_2$. The influence of elevated CO2 on microbial responses related to C-, N-, and P-cycling has been demonstrated by the increased activities of oxidative enzymes (which degrade resistant SOM) and enzymes involved in N and P mineralization (chitinases, peptidases, and phosphatases) in response to the gaseous atmosphere. Conversely, no response or decreased activity was observed for C-degrading enzymes (Burns *et al.,* 2013). Because of the extracellular enzymatic activity, the addition of labile substrates through enhanced rhizode position can thereby promote the breakdown of more resistant SOM. Distinct ecosystems may see distinct effects, though (Aamir *et al.,* 2019). This, in turn, contributes to organic matter accumulation. On the other hand, in the substrate limited arid systems, photo degradation of surface litter reduces soil input, low redox potentials of phenols due to alkaline pH, and active oxidative enzymes due to arid conditions lead to increased decomposition of recalcitrant C compounds (Burns *et al.,* 2013).

The nature and kinetics of the target enzyme being assayed determine the potential positive or negative effects of warming (Zhang *et al.,* 2015). Warming increased soil enzyme activities in winter, when soil moisture was at its highest, and in spring, when biological activity was at its peak. Sardans *et al.,* (2008) observed differences in mass-specific enzyme activity among seasons and treatments, indicating that the size and activity of microbial biomass did not directly control enzyme production. Mass-specific enzyme activity increased with temperature from low to medium warming and declined at higher temperature, suggesting that enzyme production increased with temperature. In general, enzyme activity increases with temperature (up to some optimum) and so at least theoretically the rate of enzymatically catalyzed reactions will increase due to warming, assuming that enzyme pool sizes remain constant (Burns *et al.,* 2013).

In a study by Zhang *et al.,* (2015) warming enhanced phosphatase activity (36%) but inhibited the cellulose activity (30%) in grassland ecosystem. In addition, warming caused reduction in soil C (7%) and available P (20%). Changing seasonal precipitation patterns may increase drying/wetting events in the soil. The diffusion of enzymes, substrates, and reaction products in the soil depend on soil texture and moisture. Under low moisture conditions, in situ enzyme activities are low although in some micro sites where solute concentration increases within pore spaces may exhibit high activity. Prolonged droughts are likely to decrease enzyme production resulting in lower measured activities. However, slower enzyme turnover in dry soils, along with continuous production (even at low rates) could lead to increase in pool size during a drought (Sardans and Peñuelas, 2005).

On the other hand, decreased microbial biomass could lead to a decrease in enzyme production and a decline in the relative abundance of different types of enzymes. Whereas under prolonged precipitation, enhanced plant growth and rhizode position result in increased enzymatic activities. The net effect on enzyme activity depends on how both enzyme production and turnover are affected by changes in climatic conditions. The complexity of interactions between different climatic factors and soil properties makes it difficult to pinpoint the effect of a single a biotic factor on a particular soil enzyme (Steinweg *et al.,* 2013). The rate at which SOM is decomposed is strongly affected by temperature and moisture, and thus should be sensitive to climate change (Davidson *et al.,* 1998). While heterotrophic respiration is widely used as a proxy for decomposition, the relationship between a biotic drivers and decomposition rates is driven by a series of under-lying microbially mediated processes (Conant *et al.,* 2011; Ekschmitt *et al.,* 2005). Thus, it is important to examine the response of enzyme activities to climate change in order to improve our ability to predict carbon fluxes under future climate regimes. The rate of *in situ* enzyme activity is directly responsive to temperature and moisture (Allison and Treseder, 2008) but is also controlled by enzyme pool size. Enzyme pool size is controlled by the rate at which enzymes are produced by microbes relative to the rate at which they are degraded in the environment.

The production of enzymes incurs accost to microbes in terms of both energy and nutrients. Thus, the production of enzymes should be governed by the economics of the amount of resources gained for each enzyme produced (Allison *et al.,* 2011). To maintain the stoichiometry of their biomass (driven by the fixed stoichiometry of cellular components) (Clevel and Liptzin, 2007), microbes produce enzymes targeting specific compounds that are rich in nutrients (Sinsabaugh *et al.,* 2009). However, enzyme production declines for temperature and moisture can affect both the overall rate of enzyme production as well as the relative rate of production of different enzymes due to effects on enzyme efficiency, substrate availability, and microbial efficiency. Thus, changes in the soil microclimate, whether they occur within hours, weeks, seasonally, or over decades in response to climate change, will affect enzyme pool sizes. In response to increased activity of the extant enzyme pool as soil temperatures increase, given available substrate, microbes may allocate fewer resources to enzyme production if microbial biomass remains unchanged (Allison and Vitousek, 2005). Several studies have found that N-degrading enzymes have lower temperature sensitivities than C-degrading enzymes (Stone *et al.,* 2012). This could result in increasing N limitation as soils warm, spurring microbes to increase the production of N-degrading enzymes and decrease the production of C-degrading enzymes. Soil moisture affects the diffusion of substrates, enzymes and the products of enzyme activity, and thus drought conditions could impose diffusion limitations on enzymes and substrates (Allison, 2005). In oxic soils, drought could decrease enzyme production as biomass declines, or increase production to satisfy nutrient requirements of the biomass (Allison and Vitousek, 2005).

## Change in total microbial biomass

The introduction of molecular techniques has greatly facilitated the study of microbial diversity in recent years. These techniques enable predictions regarding functionality as well as the assessment of changes in community composition and diversity of functional groupings or taxa. Blankinship *et al.,* (2011) investigated changes in the number of microbial functional groups and the makeup of microbial communities as a result of climate change in their meta-analysis. The impact of climate change on soil microbial communities varies greatly, and although the amount of research on the subject is increasing, few clear patterns have come to light. The effects of rising atmospheric $CO_2$ and global warming have been researched the most, and certain recurring trends have been found. It has been demonstrated that elevated $CO_2$ increases the exudation of sugars, organic acids, and amino acids that are easily broken down, which in turn promotes microbial activity and the mineralization of soil organic matter (Duan *et al.,* 2015). The biomass of Archaea and other microbial species, such as AMF and decomposer fungus, is also increased by it. Only a small number of research has examined how different bacterial taxa react to increased $CO_2$. Notably, increasing $CO_2$ causes an increase in beta-proteobacteria and bacteroidetes, which are copiotrophic bacteria with high nutritional requirements and growth rates that preferentially eat labile organic C (Fierer *et al.,* 2006). By contrast, when nutrient supply is low, oligotrophic acidobacteria can outcompete copiotrophs because of their slow growth rates (Fierer *et al.,* 2006).

Warming generally results in higher rates of soil microbial activity, plant respiration and photosynthesis, and soil respiration rates (Wu *et al.,* 2011). Warming increases microbial abundance and has an effect on soil microbial communities that is comparable to that of high $CO_2$. Andersen *et al.,* (2013) reported that while some research indicates a decline in bacterial diversity with warming, others show no effect on fungal diversity. Lastly, there is evidence that, as temperatures rise, the number of genes that cycle carbon and nitrogen increases, promoting the rate at which carbon and nitrogen cycle (Duan *et al.,* 2015). Drought can have a significant impact on the microbial communities in soil, causing abrupt drops in their biomass and activity as well as a flush of microbial activity and rates of C and N mineralization upon rewetting. The majority of studies on climate change have traditionally focused on rising CO2 and warming, but it's possible that extreme events like drought and freezing will become more common and have a more detrimental effect on ecosystems and how they function (Fierer *et al.,* 2006).

Consequently, an increasing amount of research has examined how soil microbial populations respond to drought, and several distinct patterns have been seen (Schimel, 2018), where a drought favors fungal abundance over bacterial abundance, which is decreased. Additionally, there may be a decrease in bacterial diversity (De Vries *et al.,* 2018). According to Schimel *et al.,* (2007), these reactions are in line with the assumption that because fungi have thicker cell walls and more cautious development tactics than bacteria, they are more drought-resistant. Research indicates that during dry conditions, gram-negative bacteria grow more often, whereas gram-positive bacteria—which are thought to develop more slowly and have stronger cell walls—reduce. According to De Vries *et al.,* (2018), wetter soil conditions also seem to increase fungal abundance, despite the reverse consequences of drought that may be anticipated. This is likely because fungi are better adapted to anaerobic environments. In addition, methanogens and methanotrophs, which are anaerobic organisms that flourish in damp environments, appear to benefit from the diversity and abundance of Archaea.

## Mechanisms undertaken by microbes to overcome the effects of climate changes

Factors related to climate change, such as increased atmospheric CO2, changed temperature patterns, and warming, affect soil microbial communities directly and indirectly. Indeed, significant changes occur in the terrestrial microbial population as a result of multiple elements changing simultaneously as a result of climate change (Castro *et al.,* 2010). According to Classen *et al.,* (2015), large-scale shifts brought about by climate change may have a substantial effect on plants, soil carbon balance, microbes, and plants alike. But interactions between different climate change factors can also be selective toward specific soil microorganisms, changing the community and ultimately determining how ecosystems will develop in the future (Castro *et al.,* 2010).

## Changes in diversity

Changes in soil microbial diversity and associated processes can result from abiotic stress imposed by climate warming. Increased temperature can affect the makeup of the microbial community since different microbial groups have distinct preferred temperature ranges for development and activity (Singh *et al.,* 2010). The rate of microbial turnover, processing, and activity increases with temperature. Because these species have faster rates of growth and are better adapted to higher temperatures, the microbial community shifts in their favor (Castro *et al.,* 2010). The microbial community of the topsoil depends on these bacteria to be stable, and this population's traits are essential for preventing soil erosion. As a result, it makes sense that changes in climate affect the relative abundance and function of soil microbial communities, as microorganisms vary in their physiology, susceptibility to temperature, and pace of growth. Consequently, this has a direct impact on how these organisms' particular processes are regulated (Classen *et al.,* 2015). The warming-induced changes in the microbial community's composition can also lead to a reduction in substrate availability. It is important to note that warming is anticipated to have an impact on the abundances of bacteria and fungi (Schindlbacher *et al.,* 2011). The fact that certain microorganisms control ecological processes including methanogenesis, nitrification, denitrification, and nitrogen fixation makes this extremely important. Changes in their respective abundances, therefore, have a direct effect on how quickly these processes occur. Nonetheless, a diversity of organisms drives some coarser-scale processes (such as nitrogen mineralization), which are more influenced by abiotic variables like moisture and temperature than by the makeup of the microbial community (Classen *et al.,* 2015).

## Physiological changes

Warming increases microbial maintenance, which in turn increases the demand for microbial maintenance (respiration per biomass) (Anderson and Domsch, 2010). Warming thus causes a rise in soil respiration through accelerating soil microbial activity (Wu *et al.,* 2011). Changes in the composition of the microbial population also cause modifications in soil respiration. Temperature-induced changes in substrate availability, plant litter quality and quantity, and relative abundance of accessible carbon (Fierer *et al.,* 2005). Therefore, it is known that because of the activities that microbes perform and how sensitive their metabolism is to temperature, changes in the global environment, such as a rise in temperature, can directly affect the rates of respiration of soil bacteria (Classen *et al.,* 2015). However, until other factors like substrate and moisture become limited or the composition or structure of the forest stand is altered, changes in the composition of the microbial community and adaptations that determine an increase in soil respiration are unlikely to occur (Schindlbacher *et al.,* 2011). Temperature and soil respiration are positively connected, and low or high moisture levels may inhibit soil respiration. According to Aanderud *et al.,* (2013), it is also susceptible to variations in soil temperature and moisture brought on by variations in precipitation. In this context, enzyme activity is a crucial additional factor to take into account. It is important to note that, in order to withstand rising maintenance costs with warming, microorganisms increase resource allocation for enzyme production (to acquire more nutrients as necessary) (Wang *et al.,* 2013). Indeed, as a result of direct and indirect effects on turnover rates and microbial synthesis of enzymes, climatic change causes both long-term changes in enzyme pools and short-term changes in enzymatic activity driven by thermodynamics (Schimel *et al.,* 2007). Because temperature and moisture fluctuations have an impact on microbial efficiency, substrate availability, and enzyme efficiency, they also have an impact on the total and relative rates of enzyme synthesis. Microbes may devote fewer resources to enzyme production if microbial biomass stays constant when the activity of the extant enzyme pool is increased by a rise in soil temperature and substrate availability (Allison and Vitousek, 2005). Noteworthy, N-degrading enzymes are less sensitive to temperature than C-degrading enzymes (Stone *et al.,* 2012). The sensitivity of substrate temperature to several parameters, including moisture content, oxygen availability, and accessibility (sorption and aggregate status), is a related consideration. The relationship between temperature dependency of soil respiration and microbial growth and substrate consumption is relevant (Larionova *et al.,* 2007). Additionally, the kind of soil affects the microbiological activity of the soil, which may play a major role in this respect. Joergensen (2010) highlights the importance of temperature in relation to respiration, microbial biomass turnover, and soil organic matter. He notes that these parameters are higher in tropical soils than in temperate soils.

## Mechanisms acting through plants

Plants are important biotic factors that play an important role in this regard. They alter the rates of soil microbial respiration by releasing carbon substrates through roots (Cardon and Gage, 2006) modify soil moisture and temperature through transpiration and by providing shade (Lauenroth and Bradford, 2006) as well as by altering the amount of rainfall that reaches the soil. Moreover, the composition of vegetation determines the quality and type of plant remains, i.e., organic matter that reaches the soil and consequently the soil respiration. This can be illustrated by the difference in respiration between soils under deciduous and evergreen forests (Rey and Jarvis, 2006). The quality of the organic matter in soils of similar origin depends upon the type of vegetation cover as well as anthropogenic land use and management. This has tremendous importance as availability of readily decomposable carbon and temperature-dependent substrate releases are the main determinants of temperature sensitivity of soil respiration. Differences in temperature sensitivity of soil organic matter decomposition result in severe uncertainties in C-cycle models (Larionova *et al.,* 2007).

## Conclusion

Climate change is one of the major global challenge affecting agriculture through direct and indirect effects. Soil health is highly influenced by features of climate change such as global warming, drought and excessive rainfall, which directly or indirectly affect soil biological activity. Elevated temperature, greenhouse gases and change in precipitation were reported to be major climatic features affecting soil microorganisms. This review also assess how climate change affect abundance and diversity of major soil microbes and faunal activities. Another effect of climate change on soil microbe is reflected through soil enzymatic effect, which could hinder organic matter decomposition and microbial nutrient cycling. The paper also gave emphasize to how soil microbial resources cope with climatic change through the changes in physiological appearance and diversity change as an adaptation mechanisms. Even though climate change is reported to have positive effects on certain microbial species under some conditions, overall results from our review reveals that climate change is a danger happening to soil lives and health as well. The future works should better focus on how varying responses among soil microbes to climate changes, and effects has to be quantified under different land uses and agro ecological conditions.

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