Available online at www.climatechangejournal.org

DOI: http://dx.doi.org/10.18782/2583-4770.105 **ISSN (E): 2583 – 4770**

Emrg. Trnd. Clim. Chng. (2022) *1*(1), 37-48

Emerging Trends in Climate Change

Peer-Reviewed, Refereed, Open Access Journal

Review Article

Effect of Climate Change on Soil and Water Resources with Mitigation Strategies for Sustainability: A Review

Kumar Chiranjeeb[1]*, Rajani[2], Chhaviraj Baghel[3], Sourabh Thakur[4]

[1,3,4]Ph.D. Scholar, Department of Soil Science, CSK HPKV, Palampur, HP-176062

[2]M.Sc. (Ag.) Student, Department of PBG, OUAT, Bhubaneswar, Odisha-751003

*Corresponding Author E-mail: kumar.chiranjeeb3@gmail.com

Received: 15.02.2022 | Revised: 27.03.2022 | Accepted: 8.04.2022

ABSTRACT

Climate is the long term basis shift in weather and temperature pattern over a particular region. The climate supports the plant and microbial community growth. Still, the adverse effect can lead to the destruction of microbial and plant diversity, intense heatwaves, and loss of glacier levels with the rise in water levels causing threats to the terrestrial and marine ecosystem with occurrences of the intense drought of higher frequencies. The higher temperature degrades the soil organic matter content, which in turn declines the nutrient status of soil with alteration of soil properties, thus hampering soil health condition. The crop growth and sustainability in the agricultural production system also hampers by affecting plant and microbe's interactions with each other and their reduced biodiversity in respective ecosystems. Water resources play a key role in ensuring proper crop growth, maintenance of soil system, and proper biological functions, and in response to this climate change, water resources are degrading. Climate change alters the enzymatic and other key functionaries in soil and associated ecosystems; thus,, monitoring the the impact of adverse climate effectseffects should be checked for sustainability in agriculture.

Keywords: *Climate, Temperature, Sustainability, Organic matter, Soil, Water, Resources.*

INTRODUCTION

Climate change refers to any variation or changes that might happen in the general climate trend over some time, either due to natural factors or anthropogenic factors (Intergovernmental Panel on Climate Change, IPCC, 2007). According to Framework Convention on Climate Change (FCCC), climate change is the change of climate or alteration in climatic situations either caused indirectly or directly by natural and human activities. The Concentration of global warming gases like carbon dioxide, methane and nitrous oxide gas has increased by a huge amount if we compare it to the preindustrial period.

Cite this article: Chiranjeeb, K., Rajani, Baghel, C., & Thakur, S. (2022). Effect of Climate Change on Soil and Water Resources with Mitigation Strategies for Sustainability: A Review, *Emrg. Trnd. Clim. Chng. 1*(1), 37-48. doi: http://dx.doi.org/10.18782/2583-4770.105

It has been reported that the carbon dioxide concentration increased at the rate of 1.9 ppm per year from 1995 to 2005, and the rate of variability changes each year (Karmakar et al., 2016). Mountain glaciers and snow cover mass have decreased in the earth system, and the sea level rose at the average rate of 1.8mm per year, which is connected to drought stress (Rahmstorf et al., 2007). The heavy precipitation rate has increased from the past to the present, with a higher water loss in water vapour form in tropical climatic conditions. Climate change is also responsible for soil erosion (Parry et al., 1999) processes, thus reducing the nutrient status in soil and ultimately declining crop production. Higher rainfall condition accelerates soil loss with negative impacts on crop growth during the different crop growth stages. Higher temperature and loss of vegetation in soil reduce the soil's organic matter status in the process of its degradation by providing suitable condition for microbes (Patil & Lamnganbi, 2018). Different land-use patterns also create situations like salinity, sodicity, and waterlogging conditions, which affect resource utilisation and reduced crop production.

Causes of Climate Change

Several factors drive the pathway for degradation or alteration in the normal climatic conditions. The changes that might happen are expressed in terms of radiative forcing, that acts as a balancing agent to analyze and stabilize the balance between incoming and outgoing radiations. The factors affecting the global climate changes are as follows:

1. Natural factors:

Natural factors such as the drift of continents, volcanic activities, the earth's tilt, and ocean currents with meteorites affect the climatic variations at a large stake. Earth's environment is always dynamic and natural autonomous. To analyze the environmental phenomena, scientists collect the samples from pollen grains, tree bark diameter and annual rings; the sea is sediments, coral reefs and snow samples.

2. Anthropogenic factors:

Human-made anthropogenic factors such as industrialization, deforestation along with pollution of different natural resources have led to enhancing the Concentration of global warming factors such as carbon dioxide, methane, water vapours etc., which in turn heat the earth's natural atmosphere (Kutílek, 2011; Carter, 2007; Bluemle et al., 1999; & Anjali & Dhananjaya, 2019).

3. Greenhouse gases:

Greenhouse gases (carbon dioxide, methane, nitrous oxide, water vapours) trap the outgoing longwave radiation from the earth's sphere and absorb incoming short wave solar radiation. This situation heats the earth's natural atmosphere and the global warming effect. The global warming potential of different gases, such as carbon dioxide, is 1; for methane, it is 24; and for nitrous oxide, it is 296. The different global warming gases and their concentrations are increasing day by day, and mainly CFCs gas concentration increase cause detrimental effect to the ozone layer and by depleting it causes U.V. light related diseases with certain types of cancers in human and animal being. This whole phenomenon is called the greenhouse effect, which leads to global warming, thus enhancing the surface temperature of the earth and causing damage to soil, crop and microbial ecosystem (Rakshit et al., 2009; & Anjali & Dhananjaya, 2019).

4. Local activities:

The local climatic influential activities also affect the macro and the regional climate to a large extent. The forest cover depletion and changes over a particular region change the temperature and rainfall pattern at large. The forest cover in the Amazon basin influence the moisture flux to the atmosphere, biosphere and regional rainfall pattern and the drought condition in Sahelian Africa region is due to the

destruction of local vegetation (Allan et al., 1995; Clausan et al., 2001; Roy & Avissar, 2002; & Karmakar et al., 2016).

Climate change effect on Global Phenomena

Earth has nearly 97.5% water source on earth in the form of oceans and rivers, which covers almost two-thirds of the continent, and only 2.5% occur as freshwater. The snow and other glacier water sources are unavailable for their use. The alteration in the water sources, glacier content, and cloud coverage (Bates et al., 2008) affect the radiation emission and its balanced distribution over the globe, thus causing climatic changes towards the emission of different greenhouse gases; thus impact of this climate change cause stress conditions on various water sources in future. Now almost 40-45% of countries on a global scale are affected by water stress, and still, it is increasing at an alarming rate; it has been estimated that by the end of the year 2050, 2/3rd of the entire population will be affected by the water stress condition (Gosain et al., 2006). These climate changes lead to global warming in which evaporation of water sources into the atmosphere alters ocean currents like El Nino and La Nina, which changes the rainfall pattern, flooding chances, and drought situation over a region for a long time. Climate change has become a serious concern on a regional and global platform, which affect the quality and quantity of water sources (IPCC, 2014). A recent report published by Intergovernmental Panel on Climate Change (IPCC) said that the average temperature of the earth will rise between 1.1 and to 6.4oC by the year 2090–2099 as when compared to 1980–1999 when the temperature rise was 2-3oC lower than the projected temperature (Goa & Zewude, 2021).

Factors influencing climate change and its Impact on Resources

The dominant water sources and their availability are affected by precipitation pattern, evaporation demand, the temperature of water sources, and wind speed with humidity level in the atmosphere. Climate change affects the associated environment with it and also the soil ecosystem. Therefore, threats to the soil ecosystemefore, affect food security (Lal, 2010; Blum & Nortcliff, 2013 & Brevik, 2013) and crop production at large with changes in soil physical, chemical and biological properties with various soil processes. Variable rainfall and temperature patterns affect the amount of evapotranspiration rate and nature with the extent of surface runoff. Among other continents, Sub-Saharan African agriculture faces a large challenge in water stress, and almost 90% of its area is now rainfed in nature to produce food. In Sub-Saharan Africa, it has been estimated that by the end of the year 2050 (Warburton et al., 2011), rainfall could drastically reduce by 10%, which could worsen the water stress condition and livelihood, and the drainage would reduce by 17% (Anil, 2014).

The various hydrological responses can influence and control the water stress condition and give a good response to climate changes which is also related to mostly land-use patter and cover (Warburton et al., 2011; & Warburton et al., 2005). Other factors such as deforestation, industrialization, lack of water reservoirs, water wastages, heavy tillage and application of pesticides, fertilizer etc., directly or indirectly affect climate change and cause detrimental effects on various ecosystems. The climatic changes and their consequences are faced by terrestrial and social systems (Sohoulande & Singh, 2016).

Climate Change Effect on Water Cycle and Resources

The water cycle describes the various forms of water, i.e. liquid, vapour and solid form with its energy exchange with the atmosphere for its conversion from one form to another and its movement in a cyclic manner in a continuous manner

between ocean, land and atmosphere. The water cycle depends on the extent and amount of precipitation, evaporation, runoff pattern, groundwater, and storage. The changes in the water cycle pattern that leads to the instability and destruction of the natural pattern of the water cycle also threaten the stability of the existence of human and natural ecosystems. Rising global temperature will cause drier zone formation, and heavy precipitation will lead to flood situations, which may alter the responses of water sources to changing climate conditions. It has been estimated that climate change over the 21st century will reduce the surface water and groundwater sources in dry subtropical regions, which will increase the competition among various water sources, and the strongest ocean warming is found in tropical and Northern Hemisphere subtropical regions (IPCC, 2014). The changes in temperature patterns and precipitation occurrences lead to a decline in groundwater recharge, leading to drought and other abiotic stresses in the environment. The changes in the water quantity might affect the marine environment, and its ecosystem is severely affected. Climate change severely affects the economic and social development of major developing countries, such as water, agriculture, fishery and tourism, etc. (Munang et al., 2013).

Climate Change Effect on Soil and Soil Resources

Soil is a natural three dimensional, dynamic body which provides habitat for billions of microorganisms for their habitat and supports plant growth by supplying essential nutrients. The soil now being considered a key resource for the entire earth's ecosystem, and we need to analyze the impact of climate change as well as vegetation and pollution on the soil system; along with it, we also need to ensure the soil provides benefits to the human and natural ecosystem (FAO & ITPS, 2015). Various soil processes are responsible for climate changes, regulate the emission of greenhouse gases, control particulate matter concentration in the environment, maintain thermal, and moisture Concentration as well as adversely affect the air quality index (Schmidt et al., 2011). The drainage pattern of organic Soil and other cultivable Soil is responsible for the emission of at least 10% of total greenhouse gases. Effect of climate like temperature when it is in favourable range for microbes helps in degradation of organic matter, and microbes respire carbon dioxide back to the atmosphere. Thus, the fixed form of carbon is released back again along with the release of methane gas the atmosphere. Higher temperatures and other fire events degrade the organic matter, and the remaining burning or charred materials persist in soil for a longer duration (Lehmann et al., 2015). Land use pattern alters the nature of the soil to act as whether sink or source and affect the climate change. The higher the temperature, the higher the degradation rate of organic carbon in the soil, while the drought has the opposite behaviour towards decreasing organic carbon status in soil. The organic matter status in soil controls soil fertility status, in which carbon and nitrogen are the important components of organic matter. Climate change impacts soil nutrient status, formation and various transformation processes, and the impact on soil's physical, chemical and biological properties. Higher temperatures favour more pronounced vegetation growth, which in turn leads to more carbon stock in the soil system (Brevik, 2012); the higher temperature also increasesincreases the decomposition and mineralization processes, decreasing the organic carbon or organic matter status in soil. The addition of organic matter in soil releases more carbon dioxide by microbial degradation of organic matter. This organic matter helps improve soil health and other soil properties for sustainable agriculture. Higher carbon dioxide in the atmosphere helps in more plant growth and production by enhancing

the rate of photosynthesis. The carbon content increase can lead to more carbon sequestration in soil and increase the carbon stock on a global level.

Impact of Climate Change on Soil Formation and Different Properties

Soil is dynamic, and its formation, like 1cm layer of soil formation, takes thousands of years of the process of weathering. Weathering is the disintegration and decomposition of rocks and minerals in nature, which leads to the formation of fine particle soil (Brady & Weil, 2008). Climatic factors such as rainfall, temperature, vegetation, topography, wind speed, and microbial activities help and regulate the soil formation processes. The changes in external factors such as climate influence the internal transformation of the soil, and this climate change will produce the necessary energy for the degradation or destruction of mineral matter present in rocks, which can lead to lower fertility status of the soil. Water or moisture concentration with carbon dioxide is essential for the chemical weathering process of soil. The Concentration and transformation due to climate change cal lead to the development of different soil profiles or soil horizon development.

Effect of Climate Change on Soil Physical Parameters

The process of transformation, gain, loss and movement of various resources, i.e. air, water, organic matter, silicate and clay matter, defines the physical processes of Soil (Brady & Weil, 2008). The change in climate conditions, such as heavy rainfall and temperature etc., alters the organic matter accumulation process and its transformation in soil. The change in climatic factors also influenced different physical processes (Benbi & Kaur, 2009), such as salinization, moisture availability, nutrient status and dynamics of carbon and nitrogen in the soil, which influence and control all important processes in soil. The effects of climate change on various soil physical processes are as follows:

A. Soil Texture, Soil Structure and Aggregate Stability

Soil texture

Soil texture consists of the relative proportion of sand, silt and clay particle in a soil system. The climate affects the soil texture directly under arid, semi-arid, sub-humid and humid climate condition as climate also influence various processes for textural classification of Soil (Brinkman & Brammer, 1990; Scharpenseel et al., 1990; & Patil & Lamnganbi, 2018).

Soil Structure and stability of soil aggregate

The arrangement of primary soil particles determines the structure of the soil. Soil structure influences the nature and amount of organic matter accumulation in soil, air, and water in soil pore space. Aggregates are the compact structure formed by combining soil particles (Dalal & Moloney, 2000; & Moebius et al., 2007). The resistance of soil aggregate towards climate change, such as high rainfall and loss of organic matter condition, affect stability, as well as the formation of aggregates and different chemical, biological, and management practices also influence aggregate formation in Soil (Stavi et al., 2022; & Patil & Lamnganbi, 2018). Due to high temperature, lower organic matter content in soil leads to lower infiltration rates, susceptibility towards compaction, high runoff, and an increase in erosion of Soil (Bot & Benites, 2005; & Karmakar et al., 2016).

B. Porosity

Pore spaces such as macro and micropores in the soil provide the soil to store moisture that leads to proper plant growth (Reynolds et al., 2002; & Patil & Lamnganbi, 2018) and exchange air between soil and the atmosphere. The pore space also influences bulk density, water availability to plants, and aeration capacity of the soil. Various enzymatic activities and root development in soil are closely associated with pore space size and its distribution in soil. The climate change

scenario affects the pore space distribution in soil, thus hampers the plant growth, reduced root extension and exudates secretion, and reducing soil aggregate stability.

C. Soil Temperature

Soil temperature controls the microbial activity, nutrient transformation with the release, nitrification rate, decomposition of organic matter, and chemical weathering in soil. Higher temperature leads to acceleration of soil processes and affects soil microbial diversity in Soil (Patil & Lamnganbi, 2018). The soil temperature is affected by the types of vegetation formed on the soil surface. The loss or gain of solar radiation is the major source of soil temperature. The conduction, convection and radiation processes help transfer heat from one system to another system (Karmakar et al., 2016).

D. Bulk Density

Bulk density is inversely related to pore space, and it is very harmful from plant growth and plant standpoint of view in soil. Bulk density is also affected by organic matter and organic carbon status in soil. The higher temperature condition leads to a decline in soil organic matter status due to the rapid decomposition process, which leads to an increase in the bulk density of soil. Higher bulk density forms surface soil compaction and correlates with other abiotic stress conditions (Birkas et al., 2009; & Patil & Lamnganbi, 2018).

Effect on Soil Chemical Properties

A. Soil pH

Soil pH is the measure of acidity or basicity of soil, which controls crop production in particular. Soil pH is not directly affected by the climatic conditions such as higher temperature or higher carbon dioxide concentration in soil. Still, climate change also affects organic matter status, carbon and nutrient dynamics, and plant water availability, thus influencing crop production and ultimately affecting soil pH (Reth et al., 2005; & Anjali & Dhananjaya, 2019).

B. Electrical Conductivity and Cation Exchange Capacity

The electrical conductivity measurement of soil measures the level of salinity. Salt concentration in soil solution affects the root growth and plant growth, permitting only limited crop growth. Different soil and crop management practices reduce or control the salt concentration. Higher temperatures and fewer rainfall conditions lead to salt accumulation in the soil surface zone, thus increasing the electrical conductivity in arid zones (Gil et al., 2009). Cation exchange capacity controls the cation exchange process and its Concentration on clay colloids. The major cations such as Ca2+, Mg2+, K+, Al3+ and Mn3+ on clay colloidal complex and its exchange with soil solution (Davidson & Janssens, 2006). Higher temperature decreases the soil organic matter status, which directly affects soil cation exchange capacity and declines nutrient exchange.

C. Nutrient Status and its Availability

Nutrients such as micro and macronutrients in soil affect the soil fertility and growth of crops on the soil and the assessment of environmentally hazardous conditions. Soil carbon and organic matter are the major sources of plant nutrients in the soil. Higher temperature leads to degrading soil organic matter content in the soil, which declines the nutrient status in soil; thus, lower crop productivity can be achieved. Carbon, nitrogen and sulphur (Weil & Magdoff, 2004, & Kumar & Swarup, 2012) are strongly correlated, and nitrogen content (Jastrow et al., 2005) also declines in response to adverse climate change conditions.

D. Soil Organic Matter

The elevation in temperature leads to faster decomposition of organic matter in the soil. Certain conditions such as higher rainfall, temperature, carbon dioxide, and atmospheric nitrogen support plant growth and add organic matter to the soil. Availability of a higher amount of organic matter to microorganisms depletes the

organic matter content in soil rather than being affected by climatic factors such as temperature Davidson and Janssens (2006). If we analyze the climatic condition of cold to hot climates, then a sharp declining trend in organic matter will appear. The Humus formation process declines in hot, dry conditions because of higher microbial activity in this zone (Brinkman et al., 1990). The increase in temperature helps in the aggregate formation of soil particles and enhances the activities with the efficiency of earthworms (Blume, 2011).

Effect on Soil Biological Properties

Biological parameters are considered key components of soil health and control all necessary soil transformation processes in soil. Soil provides a habitat for billions of microorganisms in the soil and organic matter in soil act as a soil food source for the growth and proliferation of microorganisms in the soil.

A. Soil Respiration

Soil respiration is directly connected with the soil system's organic matter status and microbial activity. Respiration is taken as a key indicator of microbial growth and soil health status (Chou et al., 2008). Soil respiration controls the carbon dioxide concentration in soil and the atmosphere. Higher organic matter leads to higher microbial activity and more respiration status in the soil. Higher temperature leads to low organic matter and thus lowers respiration status.

B. Microbial Biomass

Soil microbial biomass contains living biomass entities in soil and is also considered a living component of soil organic matter. Soil biomass carbon is related to most labile carbon pools and acts as an indicator of various soil changing processes with alteration of energy exchange between the soil and another ecosystem (Rinnan et al., 2007). The biomass carbon is affected slightly by the changes in climatic situations in short term conditions (Haynes, 2008 & Pregitzer et al., 2008).

C. Enzyme Activities

Enzymes and microbes present in the soil, serve to observe and indicate changes occurring within the plant-soil system (Aon et al., 2001; & Ruiz et al., 2009). The enzymes help in nutrient recycling, indicate soil conditions, and detect changes in soil properties and management practices. Enzymes also control and alter the emission of greenhouse gases, help the plant release plant growth substances for growth, and affect soil microbial communities. Lower organic matter status influences the enzymatic functions and its activities in Soil (Castro et al., 2009).

D. Mycorrhizal Association

The Mycorrhizal associations are found between higher plant roots and fungi in particular, whereas the fungi support the plant growth to a large extent by supplying nutrients to the roots of plants via its sheath or mycelia like structures. The association increases with response to elevated carbon dioxide concentration. Also, there is an increase in mycorrhizal biomass in which plants translocate more photosynthates below ground to the plant's roots. This mycorrhizal association helps this process (Goa & Zewude, 2021). The carbon assimilation and plant nutrients such as N and P concentration also enhance higher carbon dioxide concentration.

Table-1: Overall effects of climate change variables on soil processes (Goa & Zewude, 2021)

Elevated CO2 Concentration	i. More organic matter content ii. Accelerated nutrient transformation iii. Increased soil moisture and enhanced water use efficiency
Elevated Temperature Conditions	i. Loss of organic matter reduced soil structural stability ii. More soil respiration
Rainfall Variability	i. Effect on nutrient leaching, reduction of compounds with nutrients ii. Salinization, influence on nutrient availability

Climate Change Adaptation Measures

To protect the soil from its degradation, we must make decisions for proper agricultural operations with more emphasis on increasing soil organic matter status in the soil, such as incorporating organic residues in soil, applying organic sources, and reducing the application of chemical fertilizers. It has been estimated that 30-60% of the atmospheric carbon is utilized and fixed by green plants and the photosynthesis process. The soil erosion can be controlled by strip cropping, agronomic measures, contour bunding, cover cropping etc. Proper cultivation practice reduces the release of greenhouse gases, which gives safety to the environment and associated organisms, including human beings (Goa & Zewude, 2021). The carbon degrading cultivation practices should be avoided, and the inclusion of microorganisms to enhance the stable form of carbon such as humus and glomalin content by secretion and maintenance of these carbon forms by microorganisms in Soil (Patil & Lamnganbi, 2018). Higher temperature effects can be avoided and controlled by a large amount of vegetation and a decrease in land surface elevation. An increase in organic matter status in soil improves soil health and various soil processes (Goa & Zewude, 2021). Regular application of organic sources in soil build-up of humus substances in soil, enrichment of beneficial microorganisms, the release of carbon polymer compounds and improves soil physical, chemical and biological properties. Higher rainfall conditions accelerate the erosion of soil and provide growth conditions to crop plants. So higher moisture should be utilized properly to reduce the harmful effect of climate change (Patil & Lamnganbi, 2018). The stubble burning should be controlled as it increases the carbon dioxide concentration in the atmosphere, which leads to global warming and various other harmful situations on soil and water ecosystem. Erosion of Soil reduces the nutrient status in soil; thus, plant growth is declined in soil with lower fertility status. Bare soil tends to decline its organic matter content at a large scale and kill microbial biodiversity through wind and water erosion conditions. The cover crop will add organic matter to the soil and protect the soil from damage. Proper land management practices also reduce greenhouse gases and control their influx to the environment, which controls the harmful effect of climate change on soil properties, water resources, and microbial biodiversity in an ecosystem.

CONCLUSION

Climate change has emerged as a serious threat to biodiversity, different agro-ecological regions, microbial communities, and reducing sustainability in agriculture. The changes due to climate change on soil may influence soil fertility status, nutrient transformation, accumulation of toxic substances, soil health deterioration, alteration in soil properties, buffering capacity of soil with nutrients, organic matter status and its degradation process, declining stability of soil aggregates which affect the various soil-forming processes. Climate change and its effect on soil and water resources should be regularly monitored from each tropic level and agroecological region. Climate change, land use patterns and land degradation are closely related, whereas conservation agriculture in modern farming has given promising hope to minimize land degradation and instability. Climate change affects the economic crisis and thus should be tackled carefully with proper management practices.

Acknowledgement:

I would like to sincerely thank my co-authors for their support and kind gesture to complete this manuscript in time.

Funding: NIL.

Conflict of Interest:

There is no such evidence of conflict of interest.

Author Contribution:

All authors contributed equally to establishing the topic of the research and design experiment.

REFERENCES

Allan, D. L., Adriano, D. C., Bezdicek, D. F., Cline, R. G., & Coleman, D. C. (1995). Soil quality: A conceptual definition. *Soil Science Society of America Agronomy News, June 7*.

Anil, K. M. (2014). Climate change and challenges of water and food security. *International Journal of Sustainable Built Environment 3*, 153–165.

Anjali, M. C., & Dhananjaya, B. C. (2019). Effect of Climate Change on Soil Chemical and Biological Properties-A Review. *International Journal of Current Microbiology and Applied Science, 8*(02), 1502-1512. doi: https://doi.org/10.20546/ijcmas.2019.802.174

Aon, M. A., Cabello, M. N., Sarena, D. E., Colaneri, A. C., Franco, M. G., Burgos, J. L., & Cortassa, S. (2001). I. Spatiotemporal patterns of soil microbial and enzymatic activities in agricultural soils. *Applied Soil Ecology, 18*, 239–254.

Bates, B. C., Kundzewicz, Z. W., Wu, S., & Palutikof, J. P. (2008). Climate change and water. Technical paper of the Intergovernmental Panel on Climate Change. Geneva: IPCC Secretariat.

Benbi, D. K., & Kaur, R. (2009). Modelling soil processes in relation to climate change. *Journal of Indian Society of Soil Science, 57*, 433-444.

Birkas, M., Dexter, A., & Szemok, A. (2009). Tillage induced soil compaction as a climate threat increasing stressor. *Cereal Research Communications, 37*, 379-382.

Bluemle, J. P., Sabel, J. M., & Karlén, W. (1999). Rate and magnitude of past global climate changes. *Environmental Geosciences, 6*, 63–75.

Blum, W. E. H., & Nortcliff, S. (2013). Soils and Food Security. In Soils and Human Health; Brevik, E. C., & Burgess, L. C. Eds.; CRC Press: Boca Raton, FL, USA, pp. 299–321.

Bot, A., & Benites, J. (2005). The importance of soil organic matter: Key to drought-resistant soil and sustained food and production. *FAO Soils Bulletin, 78*(80), Food and Agriculture Organization of the United Nations, Rome, Italy.

Brady, N. C., & Weil, R. R. (2008). The Nature and Properties of Soils, 14th ed.; Pearson Prentice Hall: Upper Saddle River, NJ, USA.

Brevik, E. C. (2012). Soils and climate change: Gas fluxes and soil processes. *Soil Horizon 53*, doi: 10.2136/sh12- 04-0012.

Brevik, E. C. (2013). Climate Change, Soils, and Human Health. In Soils and Human Health; Brevik, E. C., & Burgess, L. C. Eds.; CRC Press: Boca Raton, FL, USA, pp. 345–383.

Brevik, E. C. (2013). Soils and Human Health: An Overview. In Soils and Human Health; Brevik, E. C., & Burgess, L. C. Eds.; CRC Press: Boca Raton, FL, USA, pp. 29–56.

Brinkman, R., & Brammer, H. (1990). The influence of a changing climate in soil properties. In: Trans. 14th ISSS Congress, Kyoto. Pp. 283–287.

Carter, R. M. (2007). The myth of dangerous human-caused climate change. In: Proceedings of the Australasian Institute of Mining &

Metallurgy New Leaders Conference, Brisbane. 61– 74.

Castro, H. F., Classen, T. A., Austin, E. E., Norby, R. J., & Schadt, C. W. (2009). Soil microbial community responses to multiple experimental climate change drivers. *Applied Environmental Microbiology, 76*(4), 999 – 1007.

Chou, W. W., Silver, W. L., Jackson, R. D., Thompson, A. W., & Diaz, A. B. (2008). The sensitivity of annual grassland carbon cycling to the quantity and timing of rainfall. *Global Change Biology, 14*, 1382–1394.

Claussen, M., Brovkin, V., & Ganopolski, A. (2001). Biogeophysical versus biogeochemical feedbacks of large-scale land cover change. *Geophysical Research Letters, 28*, 1011-1014.

Dalal, R. C., & Moloney, D. (2000). Sustainability indicators of soil health and biodiversity. In: Hale P, Petrie A, Moloney D, Sattler P. (eds.), Management for sustainable ecosystems. Centre for Conservation Biology, Brisbane, 101- 10.

Davidson, E. A., & Janssens, I. A. (2006). Temperature sensitivity of soil carbon decomposition and feedback to climate change. *Nature, 440*, 165–173.

FAO & ITPS. (2015). Status of the World's Soil Resources (SWSR) Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.

Gil, S. V., Meriles, J., Conforto, C., Figoni, G., Basanta, M., & Lovera, E. (2009). Field assessment of soil biological and chemical quality in response to crop management practices. *World Journal of Microbiology and Biotechnology, 25,* 439-448.

Goa, T., & Zewude, I. (2021). Review on climate change impact on soils: adaptation and mitigation. *International Journal of Environment and Pollution Research, 9*(2), 58-65.

Gosain, A. K., Rao, Sandhya, Basuray, & Debajit (2006). Climate change impact assessment on the hydrology of Indian River basins. *Current Science, 90*(3), 346–353.

Haynes, R. J. (2008). Soil organic matter quality and the size and activity of the microbial biomass: their significance to the quality of agricultural soils. In: Huang Q, Huang PM, Violante A (eds) soil mineralmicrobe-organic interactions: theories and applications. Springer, Berlin., 201–230.

IPCC. (2007). Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK., New York.

IPCC. (2014). Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E., Chatterjee, M., Ebi, K. L., & Estrada, Y. O. Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA.

Jastrow, J. R., Miller, M., Matamala, R., Norby, R. J., Boutton, T. W., Rice, C. W., & Owensby., C. E. (2005). Elevated atmospheric carbon dioxide increases soil carbon. *Global Change Biology, 11*, 2057 – 2064.

Karmakar, R., Das, I., Dutta, D., & Rakshit, A. (2016). Potential effects of climate change on soil

properties: A review. *Science International, 4*, 51-73.

Kumar, M., & Swarup, A. (2012). Impact of elevated atmospheric CO2 and temperature on plant-available phosphorus in Soil – Assessment using 32P tracer technique. *Journal of Indian Society of Soil Science, 60*(4), 312 - 316.

Kutílek, M. (2011). Soils and climate change. *Soil Tillage Research, 117*, 1–7.

Lal, R. (2010). Managing soils and ecosystems for mitigating anthropogenic carbon emissions and advancing global food security. *BioScience, 60*, 708–721.

Lehmann, L., Abiven, S., Kleber, M., Pan, G., Singh, B. P., Sohi, S., & Zimmerman, A. (2015). Persistence of biochar in soil. In Lehmann, J., & Joseph, S. eds., Biochar for Environmental Management. *Science and Technology*, 2nd edition.

Moebius, B. N., Van, E. H. M., Schindelbeck, R. R., Idowu, O. J., Clune, D. J., & Thies, J. E. (2007). Evaluation of laboratory-measured soil properties as indicators of soil physical quality. *Soil Science, 172*, 895-912.

Munang, R., Johnson, N., & Nkem, Z. H. (2013).Using data digitalization to inform climate change adaptation policy: Informing the future using the present; Weather and Climate Extremes; http://dx.doi.org/10.1016/j.wace.2013.07.001i.

Parry, M., Rosenzweig, C., Iglesias, A., Fischer, G., & Livermore, M. (1999). Climate change and world food security: A new assessment. *Global Environmental Change, 9*, 51-67.

Patil, A., & Lamnganbi, M. (2018). Impact of climate change on soil health: A review. *International Journal of Chemical Studies, 6*(3), 2399-2404.

Pregitzer, K. S., Burton, A. J., King, J. S., & Zak, D. R. (2008). Soil respiration, root biomass, and root turnover following long-term exposure of northern forests to elevated atmospheric CO2 and tropospheric O3. *New Phytologist, 180*, 153-161.

Rahmstorf, S., Cazenave, A., Church, J. A., Hansen, J. E., Keeling, R. F., Parker, D. E., & Somerville, R. C. (2007). Recent climate observations compared to projections. *Science, 316*, 709-709.

Rakshit, A., Sarkar, N. C., Pathak, H., Maiti, R. K., Makar, A. K., & Singh, P. L. (2009). Agriculture: A potential source of greenhouse gases and their mitigation strategies. *IOP Conf. Ser. Earth Environmental Science, 6*.

Reth, S., Reichstein, M., & Falge, E. (2005). The effect of soil water content, soil temperature, soil pH-value and root mass on soil CO2 efflux. *Plant Soil, 268*, 21–33.

Reynolds, W. D., Bowman, B. T., Drury, C. F., Tan, C. S., & Lu, X. (2002). Indicators of good soil physical quality: density and storage parameters. *Geoderma, 110*, 131-146.

Rinnan, R., Michelsen, A., Ba˚a˚th, E., & Jonasson, S. (2007). Fifteen years of climate change manipulations alter soil microbial communities in a subarctic heath ecosystem. *Global Change Biology, 13*, 28–39.

Roy, S. B., & Avissar, R. (2002). Impact of land use/land cover change on regional hydrometeorology in Amazonia. *Journal of Geophysical Research: Atmosphere, 107*, No. D20. 10.1029/2000J D000266

Ruiz, G. R., Ochoa, V., Vinegla, B., Hinojosa, M. B., Pena-Santiago, R., Lie´banas, G., Linares, J. C., &

Carreira, J. A. (2009). Soil enzymes, nematode community and selected physicochemical properties as soil quality indicators in organic and conventional olive-oil farming: influence of seasonality and site features. *Applied Soil Ecology, 41*, 305–314.

Scharpenseel, H. W., Schomaker, M., & Ayoub, A. (1990). Soils on a warmer Earth: Effects of expected climate change on soil processes, with emphasis on the *Tropics and Subtropics. 273*, Elsevier, Amsterdam.

Schmidt, M. W. I., Torn, M. S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I. A., Kleber, M., KogelKnabner, I., Lehmann, J., Manning, D. A. C., Nannipieri, P., Rasse, D. P., Weiner, S., & Trumbore, S. E. (2011). Persistence of soil organic matter as an ecosystem property. *Nature, 478*, 49-56.

Sohoulande, D. D. C., & Singh, V. P. (2016). Impact of climate change on the hydrologic cycle and implications for society. *Environment and Social Psychology, 1*(1), 36–49. http://dx.doi.org/10.18063/ESP.2016.01.002.

Stavi, I., Priori, S., & Thevs, N. (2022). Editorial: Impacts of Climate Change and Land-Use on Soil Functions and Ecosystem Services in Drylands. Frontiers in *Environmental Science, 10,* 1-2. 10:851751. doi: 10.3389/fenvs.2022.851751

Warburton, M. L., & Schulze, R. E. (2005). Detection of Climate Change: A Review of Literature on Changes in Temperature, Rainfall and Streamflow, on Detection Methods and Data Problems, pp257- 274. [In: Schulze, R. E. (ed) Climate Change and Water Resources in Southern Africa: Studies on Scenarios, Impacts, Vulnerabilities and Adaptation. Water Research Commission, Pretoria, RSA, WRC Report 1430/1/05].

Warburton, M. L., Schulze, R. E., & Jewitt, G. P. W. (2011). Hydrological responses to joint land-use change and climate change in three diverse South African catchments. Submitted to Global and Planetary Change.

Weil, R. R., & Magdoff, F. (2004). Significance of soil organic matter to soil quality and health. In: Weil, R. R., & Magdoff, F. (eds) Soil organic matter in sustainable agriculture. *CRC Press*, Florida. 1–43.