Int.J.Curr.Res.Aca.Rev.2022; 10(01): 91-100

International Journal of Current Research and Academic Review

ISSN: 2347-3215 (Online) Volume 10 Number 01 (January-2022)

Journal homepage: http://www.ijcrar.com

doi: https://doi.org/10.20546/ijcrar.2022.1001.010

Impact of Climate Change on Soil quality and Health: A Review

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Abstract

Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. Variable and changing climate will influence soil properties, including pH as a master variable that affects all other properties of an ecosystem. Climate change has a potential impact on the soil health through physical, chemical and biological properties of soil. Climate change is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climatic variability observed over comparable time periods. Soil health has been described as integral to the concept of sustainable agriculture. Soil health is a composite set of measurable physical, chemical and biological attributes related to functional soil processes, which can be used to evaluate soil health status as affected by management practices and climate change. Defining soil health in relation to climate change should consider the impact of range of predicted global change drives such as rising atmospheric carbon dioxide levels, elevated temperature, altered precipitation and atmospheric nitrogen deposition on physical, chemical and biological functions of soil. There is little knowledge about specific effects of altered temperature and rainfall patterns on soil properties; it points to highly variable responses in dependence on initial soil and ecosystem properties. Improved understanding of the effects of changing and variable climate on soil health and soil quality is urgently needed to inform management decision to prevent loss of environmental function in soils and terrestrial ecosystems.

Article Info

Received: 05 December 2021
Accepted: 15 January 2022
Available Online: 20 January 2022

Keywords

Climate change, soil health, soil quality, soil properties.

Introduction

Climate change is a major threat to sustainable growth and development in world especially developing countries are the most vulnerable to climate change impacts because they have fewer resources to adapt: socially, technologically and financially, it is particularly vulnerable to the effects, including reduced agricultural production, worsening food security, the increased incidence of both flooding and drought, spreading disease and an increased risk of conflict over scarce land and water resources. The Intergovernmental Panel on Climate Change (IPCC) predicts that during the next decades, billions of people, particularly those in developing countries, will face changes in rainfall patterns that will contribute to severe water shortages or flooding, and rising temperatures that will cause shifts in crop growing seasons.

This will increase food shortages and distribution of disease vectors, putting populations at greater health and life risks. The predicted temperature rises of 1 to 2.5o C by 2030 will have serious effects, including reduced crop yield in tropical areas. The impact of a single climate-, water- or weather-related disaster can wipe out years of gains in economic development. Climate is a very important factor affecting soil erosion. Previous studies have demonstrated how soil erosion can increase when climate becomes more arid (Lavee *et al.,* 1991; Calvo *et al.,*1994).

Climate change, its impacts and vulnerabilities on agriculture and associated sector is a matter of big concern in the current era (Goyal, 2004; Kumar *et al.,* 2004; Mimi and Jamous, 2010; Verge *et al.,* 2007; Wani *et al.,* 2013).Climate plays a major role while attaining potential yield or maximum yield (Karmakar *et al.,* 2016). The main potential changes in soil-forming factors (forcing variables) directly resulting from global change would be in organic matter supply from biomass, soil temperature regime and soil hydrology, the latter because of shifts in rainfall zones as well as changes in potential evapotranspiration. Soil changes because of a potential rise in sea level resulting from a net reduction in Antarctic ice cap volume and ocean warming are discussed in Brammer and Brinkman (1990). Additionally, the biggest single change in soils expected as a result of these postulated forcing changes would be a gradual improvement in fertility and physical conditions of soils in humid and sub humid climates. Certain tropical soils with low physico-chemical activity may undergo a radical change from one major soil-forming process to another (Sombroek, 1990). Soil health indicators are a composite set of measurable physical, chemical and biological attributes which relate to functional soil processes and can be used to evaluate soil health status, as affected by management and climate change drivers. Since soil has a major role in supplying macro and micro nutrients to all kinds of crops grown on it, studies on change of its physical, chemical and biological properties with respect to climate is important.

Defining soil health in relation to climate change should consider the impacts of a range of predicted global change drivers such as rising atmospheric carbon dioxide (CO2) levels, elevated temperature, altered precipitation (rainfall) and atmospheric nitrogen (N) deposition, on soil chemical, physical and biological functions (French *et al.,* 2009). Therefore, the general objective of this review is to review the impact of climatic change on soil quality and soil health.

Soil and Climate Change

Soil is a part of the natural world that is both affected by and contributing to global warming. Soil is the one of the largest sources of carbon in the world. It is primarily accumulated through plants which 'fix' the carbon from carbon dioxide in the air; the soil then directly absorbs the carbon as the plants decay. Additionally, dead leaves and animals are broken down by microbes in the soil and carbon is accumulated. Although the earth's climate has been slowly evolving over millions of years, rapid changes have occurred in recent times due to the activities of humans. Climate change is now recognized as something which is affecting all our lives. One of the biggest known causes of climate change has been the burning of fossil fuels such as coal and oil. These substances release carbon dioxide and other gases, which build up in the atmosphere and trap more of the sun's energy. This is often called the 'greenhouse' effect, and causes global warming, a condition which is resulting in temperatures rising all over the world. Rainfall patterns are also changing, with some regions becoming drier and others becoming wetter and more vulnerable to flooding.

Soil is an important part of the water cycle (or hydrological cycle) the balances of this will also be affected by climate change. We know climate change will affect the lives we lead and the places we live. Current infrastructures, such as buildings and roads, will almost certainly have to change to meet new climatic conditions. Overall climate change will have a huge effect on the functions soil performs, and this therefore have a major influence on the future use of soils, often requiring significant adaptations to meet the changing climate (Robert b.m. and wimg. sombroek 01, nov.2016).

Climate change and its impacts increases in temperature, changing precipitation patterns, floods, and droughts will not only affect us but may also affect how soil provides these services. Soil carbon sequestration cannot be alone the solution due to the limited magnitude of its effects and its potential reversibility. It could play an important role in climate mitigation in the short term together with other measures, especially because of its immediate availability and the relatively low cost. Soil carbon losses are driven by changes in land use especially drainage of peat lands, land management and climate, which may lead to soil degradation and the loss of soil organic matter.

Climate change is expected to have an impact on soil (EEA, 2009a; EEA, 2009b; EEA-JRC-WHO, 2008). However, the interrelations between climate change and changes in soil quality are complex and still under study. As a consequence, predictions, which are based on hypothetical scenarios and data obtained under controlled conditions, are still more qualitative than quantitative. But it is clear that tackling climate change cannot be done without a better understanding and management of our soils.

Climate change can have a very big impact on soils and the functions that soil performs. In agriculture, climate change will affect crop production as changes in soil; air temperature and rainfall affect the ability of crops to reach maturity and their potential harvest (JRC-WHO, 2008). As the climate heats up, reductions in the amount of water available may be made up initially by irrigation. However, scarcity of water may prevent water being used for irrigation. Increasing damage to the land, or land degradation, will occur in the form of soil erosion, desertification, salinization, or loss of peat soils, further impacting on the capability of soils to support the needs of agriculture.

Soil and Soil Health

Healthy soil is very important for human health because what is in the soil affects the health and quality of the food, we eat that is derived from it. For example, soil is the main source of trace elements (e.g., iodine and cadmium), which are taken up by crops and plants, before being consumed by us. However, the human body only needs tiny amounts of these trace elements – too much or too little can make us ill. Factors such as soil acidity can affect the quantity of trace elements passing to crops, which subsequently affects us as well. A common example is a lack of iodine, which causes problems with the thyroid gland (vital for human growth and development). In contrast, too much cadmium can cause kidney failure.

An intensive agricultural practice during the post green revolution era without caring for the environment has supposedly played a major role towards enhancement of the greenhouse gases. Due to increase in demand for food production the farmers have started growing more than one crop a year through repeated tillage operations using conventional agricultural practices (Patle *et al.*, 2013b). It's contributed to the emission of three major greenhouse gases viz., carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) (West and Marland, 2002). Reason behind the global increase in CO_2 concentrations are mainly due to use of fossil fuel and land use change, CH4 concentration is predominantly due to agriculture and fossil fuel use and N2O concentration is primarily due to agriculture (Lal, 2004a).

Climate change and its environmental consequences

The changing temperature regime would result in considerable changes in the precipitation pattern. If temperatures rise, as forecasted, an increasing number of mountain glaciers, the permafrost soil zone and the polar ice caps will melt. This would lead to changes in the water flow dynamics, including flood waves and surface runoff, resulting in a rise of sea level, threatening low-lying, man-protected lands, settlements, agricultural areas etc (Scharpenseel *et al.*, 1990; Szabolcs, 1990; Várallyay, 1994). A changing climate will result in considerable changes in natural vegetation and in land use practices. These changes in turn result in a feedback effect on climate: modified albedo, surface roughness, micro-circulation processes, the heat and energy balance of the near-surface atmosphere and the temperature and precipitation pattern considerably influence the field water cycle and soil formation/degradation processes. (Várallyay, 1998, 2002, 2007, 2009a; Harnos & Csete, 2008; Várallyay & Farkas, 2008).

Climate Change Impact on Soil Functions

The potential impact on soil health resulting due to the climate change is through organic matter supply, temperature regimes, hydrology and salinity. Climate change may also adversely impact soil health and quality by reducing the amount of organic matter in the soil, harming the structure of the soil; and increasing its vulnerability to erosion and other degradation processes. Following are the major consequences of global climate change on soil health and quality.

Climate change effect on Soil Formation and processes

The impact of climate change on soils is a slow complex process as because soils not only be strongly affected by climate change directly (for example effect of temperature on soil organic matter decomposition and indirectly, for example changes in soil moisture via changes in plant related evapotranspiration. Soil formation is controlled by numerous factors including climatic factors such as temperature and precipitation. These parameters of climate influence the soil formation directly by providing biomass and conditions for weathering. Main parameters of climate that directly influence on soil formation are sum of active temperatures and precipitation-evaporation ratio (Pareek, 2017). They determine values of energy consumption for soil formation and water balances in soil, mechanism of organic-mineral interactions, transformation of organic and mineral substances and flows of soil solutions.

Direct impacts of climate change on soil functions

Soil-climate models assuming constant inputs of carbon to soils from vegetation predicts the expected changes in temperature, precipitation and evaporation with a concomitant increase inorganic matter turnover facilitating increased losses of CO_2 in mineral and organic soils. These losses of soil carbon will also affect other soil functions like poorer soil structure, stability, topsoil water holding capacity, nutrient availability and erosion (Das, 2015).

Climate change and its hydrological consequences may result in the significant modification of soil conditions. The impact analysis of potential future changes is rather difficult, due to the uncertainties in the forecast of global and long-term temperature and precipitation patterns (including their spatial and temporal variability) combined here with the changing hydrological cycle and the complex and integrated influences of natural vegetation and land use pattern (partly due to the changes in the socio-economic conditions). Consequently, the long-term and global 'soil change prognosis' can only be a rather rough, sometimes imaginative estimation and allows only for the drawing of general conclusions. In the natural soil formation processes the pedogenic inertia will cause different time-lags and response rates for different soil types developed in various regions of our globe (Scharpenseel *et al.*, 1990; Lal *et al.*, 1994; Rounsevell and Loveland, 1994). Physical and chemical characteristics of soils can vary as climate changes. A change in certain physical and chemical characteristics of soils can have either a positive or negative effects on erosion rates.

Climate change effect on Soil structure

Soil structures controls amount of water and air present in soil. Aggregate stability, the resistance of soil aggregates to external energy such as high intensity rainfall and cultivation is determined by soil structure as well as a range of chemical, biological properties and management practices (Dalal and Moloney, 2000; Moebius *et al.*, 2007). It is considered as a useful soil health indicator since it is involved in maintaining important ecosystem functions in soil including organic carbon accumulation, infiltration capacity, movement and storage of water, root and microbial community activity.

The influence of climate change on soil structure (type, spatial arrangement and stability of soil aggregates) is a more complex process. The most important direct impact is the aggregate-destructing role of raindrops, surface runoff and filtrating water, especially during heavy rains, thunderstorms and even 'rain bombs', the increasing hazard, frequency and intensity of which are characteristic features of climate change. The indirect influences are caused by changes in the vegetation pattern and land use practices.

Climate change effect on Plant Nutrient Availability and Acquisition

Plant availability of nutrients in the soil is a function of soil chemical properties as well as location of the ion relative to the root surface and the length of the pathway the nutrient must travel in the soil to reach the root surface. Soil moisture regime plays a distinguished role. It determines the water supply of plants, influences the air and heat regimes, biological activity and plant nutrient status of soil. In most cases it determines the agro-ecological potential, the biomass production of various natural and agro-ecosystems and the hazard of soil and/or water pollution.

Increases in air temperature and changes in precipitation have significant impacts on root zone temperature and moisture regimes. It is well known that soil moisture and temperature are primary determinants of nutrient availability and root growth and development and that carbon allocation to roots governs nutrient acquisition, it is reasonable to expect that process outcomes will be reflective of the changed climate. The nature and extent of the change in these two parameters will be site- and soils specific. It has been suggested that climate change impacts on nutrient use efficiency is be primarily affected through direct impacts on root surface area and influx rate (Brouder and Volenec, 2008).

The water availability for plant growth and important soil processes are governed by a range of soil properties including porosity, field capacity, lower limit of plant available water (thus excluding osmotic potential), micro pore flow and texture (Jarvis, 2007; Reynolds *et al.*, 2002). Plant available water capacity has been used as part of integrative soil health tests to assess management impacts. Soil moisture deficit directly impacts crop productivity but also reduces yields through its influence on the availability and transport of soil nutrients. Further, more the soil available water and distribution may respond rapidly to climate change, especially to variable and high intensity rainfall or drought events and thus management strategies, could be planting of cover crops, conservation tillage and incorporation of organic matter, that maintain or even enhance water infiltration and available water in soil may help in mitigating the impact of severe rainfall and drought events or severe erosion events (Lal, 1995; Salvador Sandris *et al.,* 2008)

Drought increases vulnerability to nutrient losses from the rooting zone through erosion. Because nutrients are carried to the roots by water, soil moisture deficit decreases nutrient diffusion over short distances and the mass flow of water-soluble nutrients such as nitrate, sulfate, Ca, Mg and Si over longer distances. Even though it is more and more acknowledged that organic forms of nitrogen in soil and the rhizosphere play an important role in supplying trees with nitrogen especially in boreal and temperate ecosystems (Nasholm *et al.*, 2009), the availability of inorganic nitrogen forms, i.e., nitrate and ammonium, is still assumed to be crucial (Lucash *et al.*, 2007). Inorganic sulphate is the most important Sulphur source to be taken up by plant roots from the soil (Hersch bach, 2003), and most of the other elements are available to plants mainly in inorganic mineral forms (Marschner, 1995). Thus, any negative drought effect on the microbial mineralization activity which will in turn influence the amount of the inorganic nutrients available for plant uptake has the potential to impair mineral N nutrition of trees. Even when we might assume that organic nutrients i.e., mainly N in the form of amino acids are taken up by tree roots, microbial depolymerization of proteins/peptides is still essential (Rennenberg *et al.*, 2009).

Reduced soil water availability limits microbial activity in soils and, depending on the intensity and duration of the drought event, may lead to total inhibition of microbial metabolism (Borken and Martzner, 2009). The mobility of microorganisms in the soil as well as of the excreted exo-enzymes such as proteases decreases with increasing drought (van Meeteren *et al.*, 2008). Drought events thus cause in a first step reduced bacterial activity accompanied by dehydration and, as drought prolongs, a dieback of soil microorganisms (Schimel *et al.*, 2007). The decrease in microbial activity is related to the length and intensity of the drought period as well as to the adaptation potential of the microorganisms (Jensen *et al.*, 2003).

Beier *et al.*, (2008) reported that carbon and nitrogen mineralization were affected differently by drought; whereas decomposition of organic carbon was mainly temperature sensitive, ammonification was only slightly dependent on temperature but strongly inhibited by reduced soil water availability. It has also been observed that the amount of dissolved organic nitrogen in the soil increases during drought events, presumably due to dieback of microbial biomass (Borken and Martzner 2009, Dannenmann *et al.*, 2009).

Climate change effect on Soil fauna and soil flora

Climate change has both direct and indirect effects on the activities of soil microbes that feedback greenhouse gases to the atmosphere and contribute to global warming. Direct effects include the influence on soil microbes and greenhouse gas production of temperature, changing precipitation and extreme climatic events. Global changes such as warming are directly altering microbial soil respiration rates because soil microorganisms, and the processes they mediate, are temperature sensitive. The role of elevated temperature in microbial metabolism has received considerable recent attention (Karhu *et al.*, 2014).

Temperature changes are often coupled with changes in soil moisture, which may explain some inconsistent results how microbial communities respond to climatic change. For example, rates of microbial activity at warmer temperatures can be limited by diffusion and microbial contact with available substrate (Zak *et al.,* 1999). With small changes in soil moisture availability (<30% reduction in water holding capacity), soil fungal communities may shift from one dominant member to another while bacterial communities remain constant. These patterns indicate greater fungal than bacterial plasticity during non-extreme wet-dry cycles (Kaisermann *et al.,* 2015).

Soil temperature range of 100c -280c influence soil respiration by increasing the activity of extra cellular enzymes that degrade polymeric organic matter in soils (Conant *et al.*, 2008), increase microbial retake of soluble substrates (Allison *et al.*, 2010) and increase microbial respiration rates (Wallenstein *et al.,* 2010).

Increase in soil temperature increases the soil nitrogen mineralization rates through the increase in microbial activity and increase in the decomposition of organic matter in the soil (Yan and Hongwen, 2014). Soil temperature below freezing point decreases mineralization by inhibiting microbial activity and decreasing diffusion of soluble substrates in the soil (Kaiser *et al.,* 2007).

Climate change affect Soil Heath Indicators (Biological)

Soil biota biomass

Microbial growth and activity generally decrease with decreased temperature. Extremely high temperatures, in general, are dangerous for many microorganisms (Karmakar *et al.,* 2016) and affect their respiration, growth and biomass production.

Respiration

Increase in annual maximum and minimum temperature increased microbial respiration (Lychuk *et al.*, 2019) and hence releasing more greenhouse emissions to the atmosphere and further increasing climate.

Enzyme activity

Extreme high temperature denatures enzymes activity and very low temperature make enzymes inactive to support soil productivity and plant life. Moderate temperature required for maintaining healthy soils (Searchinger *et al.,* 2008)

Climate change affect Soil organic matter (SOM)

High temperature affects soil moisture, Soil organic matter and soil structure (Hallema, *et al.,* 2014). Soil Organic matter increases microbial biomass and catabolic activity which may directly enhance nutrient mineralization and SOM stabilization (Frost *et al.*, 2019)

Potentially mineralizable N

Increasing temperatures increase N mineralization thus have a positive effect on plant growth (Brevik, 2013) and food production

Climate change effect on Soil PH

Soil pH is a function of parent material, time of weathering, vegetation and climate. It is considered as important indicators of soil health. Soil pH has thus been included in integrative soil health tests to assess impacts of land use change and agricultural practices. Most soils would not be subjected to rapid pH changes resulting from drivers of climate change such as elevated temperatures, CO2 fertilization, variable precipitation and atmospheric N deposition. However, these drivers of climate change will affect organic matter status, C and nutrient cycling, plant available water and hence plant productivity, which in turn will affect soil pH (Reth *et al.,* 2005).

Over flooding affects soil pH

Over flooding dilute the soil solution. It should therefore favor desorption. But reduction of Al (III) and Mn (IV) hydrous oxide droftlogly alters their surface properties and produces large amount of water soluble Fe^{2+} and Mn^{2+}. Thus, ion sorbed on them may be desorbed, and exchangeable cations may also be displaced in to the solution. The increase in pH of acid soils and the decrease in pH of alkaline soils affect the surface properties of clays, hydrous oxide and organic matter. Changes in the pH may increase sorption or desorption, depending on the point of zero charge of the sorbent.

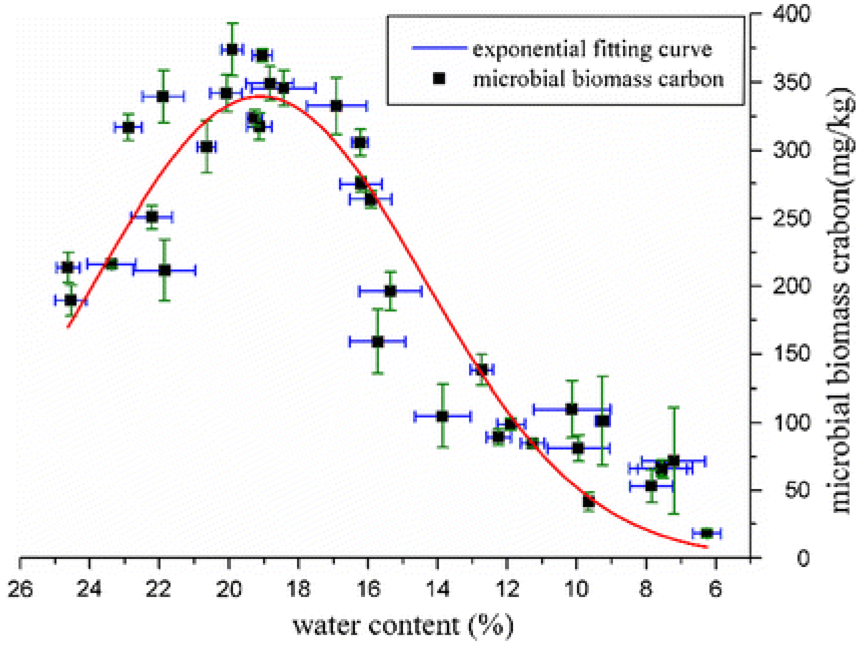
Sorption and desorption play an important role in controlling the availability of plant nutrients and pollution by toxic metal and organic pesticides (burchill *et al.,* 1981).

Temperature and rainfall affect pH

Temperature and rainfall control leaching intensity and soil mineral weathering. In warm, humid environments, soil pH decreases over time in a process called soil acidification, due to leaching from high amounts of rainfall. In dry climates however, soil weathering and leaching are less intense and pH can be neutral or alkaline. Generally, soil PH affected by temperature and heavy rainfall, as it is an important indicator of soil health. It affects crop yields, crop suitability, plant nutrient availability, and soil micro-organism activity which influence key soil processes. (Burchill *et al.,* 1981). At a soil temperature range of 250c – 390c the soil pH increases as a result of organic acid denaturation which increases at high temperature (Menzies and Gillman, 2003).

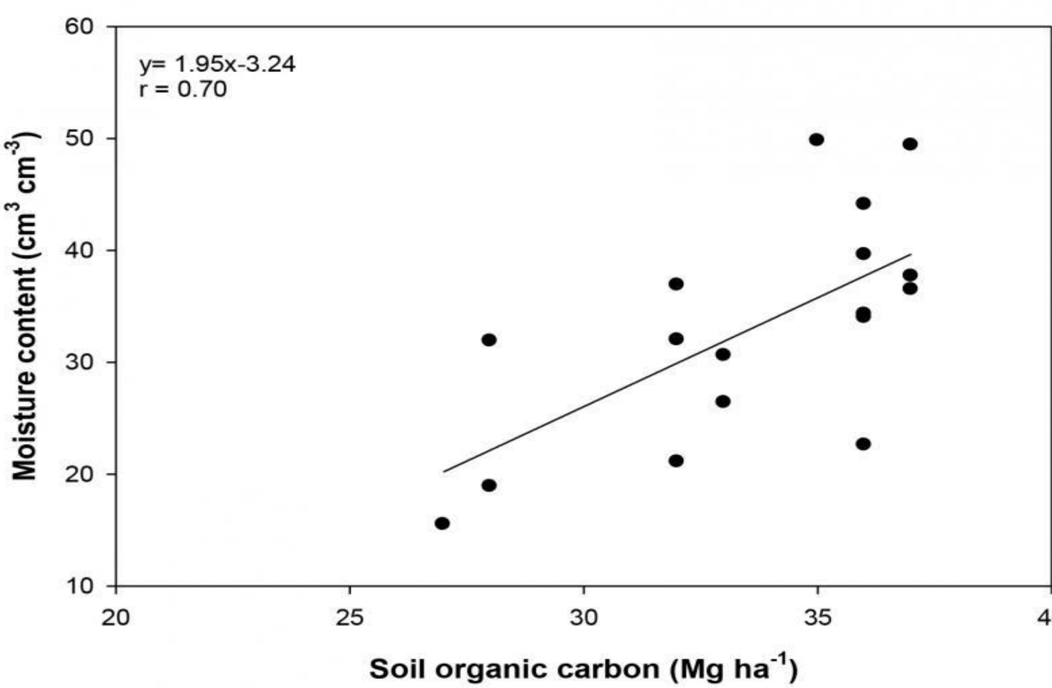
Climate change is a major threat that could lead to a decline in agricultural production in many regions of the world. Changes in average temperatures and in precipitation patterns will also influence soil organic matter.

Fig.1



Source:Seema B. Sharma and Thivakaran A. Gobi., 2016. Impact of Drought on Soil and Microbial Diversity in Different Agroecosystems of the Semiarid Zones

Fig.2



Source: Integrated Crop Management News, and Iowa State University Extension and Outreach. August 23, 2017

This in turn will affect important soil properties such as aggregate formation and stability, water holding capacity, cation exchange capacity, and soil nutrient content. Soil PH affected by temperature and heavy rainfall, as it is an important indicator of soil health. It affects soil micro-organism activity which influence key soil processes. Flooding or submerging an air-dry soil in water set in motion a series of physical, chemical and biological process that profoundly influence the soil health as a medium of plant growth. Reduced soil water availability due to drought limits microbial activity in soils and, depending on the intensity and duration of the drought event, may lead to total inhibition of microbial metabolism. We also need to know more about the effects of climate change on the soil. A better understanding of these areas is crucial to provide us with insight on how changes in soil processes and properties might influence soil erosion and food security. I conclude that climate change affects soil health and, therefore, crop yields. Appropriate use of ISFM technologies has the potential for arresting deterioration of soil health and adapting agricultural systems to the changing climate. However, the site-specific management practices for soil and water conservation, crop improvement and integrated nutrient management needs to be identified to overcome impact of climate change on physical, chemical and biological properties of soil.

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How to cite this article:

Tolossa Ameyu. 2022. Impact of Climate Change on Soil quality and Health: A Review. *Int.J.Curr.Res.Aca.Rev.* 10(01), 91-100. doi: https://doi.org/10.20546/ijcrar.2022.1001.010