Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.8, No.7, 2018 www.iiste.org

Effects of Climate Change on Soil and Water Resources: A Review

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Abstract
This review paper presents an overview of global impacts on soil and water resources as consequence of change in climate and summarizes the measures/adaptation options to minimize the risk. There is a strong scientific consensus that the earth's climate has changed and will continue to change as human activities increase the concentrations of greenhouse gases in the atmosphere. World population is increasing day by day and at the same time soil and water resources is threatened due to natural resource degradation and climate change. The recent IPCC report has clearly stated that warming of the climate system is unequivocal and it is very likely" caused by natural and human activities. Numerous scholars reported that climate change affects hydrological cycle or water cycle components, especially precipitation, evapotranspiration, temperature, stream flow, ground water and surface runoff. A change in climate can alter the spatial and temporal availability of soil and water resources. These changes will result in increased floods and drought, which will have significant impacts on the soil and water resource availability. Soils are complicatedly linked to the climate system through nitrogen, the carbon, and hydrologic cycles. Because of change in climate soil processes and properties will affected. Along with changes in temperature, climate change will bring changes in global rainfall amounts and distribution patterns. And since temperature and water are two factors that have a large influence on the processes that take place in soils, climate change will therefore cause changes in the world's soils. Water resources management can help to counter balance effects of climate change on stream flow and water availability until a certain level. This review paper starts with highlighting the studies on the impacts of climate changes on soil and water resource mainly due to change in temperature and rainfall. The impacts of climate change on soil and water resources are highlighted, and respective studies on hydrological responses to climate change are examined.
Finally the paper concludes by outlining possible adaptation options in the realm of climate change impacts on soil and water resources.
Keywords: Climate change, Soil and water resources, hydrological Cycle, soil processes and Properties

Introduction

About 97.5% of the water on earth is salt water which is present in the seas and the oceans. Fresh water accounts for only 2.5%. Of this fresh water, 68.6% is in the form of ice and permanent snow cover in the Arctic, the Antarctic, and mountain glaciers. 30.1% is in the form of fresh groundwater. Only 0.3% of the fresh water on Earth is in easily accessible lakes, reservoirs and river systems (Peter HG, 1993). Globally, changes in water vapour content of the atmosphere, cloud cover and ice influence the radiation balance of the earth and thus play an important role in determining the climate response to increasing greenhouse gas emissions (Bates et al. 2008). The global water stress increasing from time to time. For instance, in 1955, only seven countries were found to be with water stressed conditions. In 1990 this number rose to 20 and it is expected that by the year 2025 another 10–15 countries shall be added to this list. It is further predicted that by 2050, 2/3rd of the world population may face water stressed conditions (Gosain et al., 2006).

Global warming increases the evaporation of water into the atmosphere and changes the patterns of major airstreams and ocean currents such as El Nino and La Nina. This in turn alters the distribution of precipitation, so some regions experience greater rainfall and flooding while others become more prone to droughts (Open University, 2016). In recent years the study of the effects of climate change on the quantity and quality of water resources has attracted a great deal of attention, particularly at a regional and global scale (IPCC, 2014). The most recent report of the Intergovernmental Panel on Climate Change (IPCC) indicates that the average global temperature will probably rise between 1.1 and 6.4°C by 2090–2099 as compared to 1980–1999 temperatures, with the most likely rise being between 1.8 and 4.0°C. The most dominant climate drivers for water availability are precipitation, temperature and evaporative demand (determined by net radiation at the ground, atmospheric humidity and wind speed, and temperature). The change in climate there will be effects on the environment, including the soil (Brevik, 2012). Soils are also important to food security (Lal, R. 2010; Blum and Nortcliff, 2013 and Brevik, 2013) and climate change has the potential to threaten food security through its effects on soil properties and processes (Brevik, 2013). Changes in rainfall and temperature have a direct effect on the amount of evapotranspiration and on both quantity and quality of the surface runoff. Consequently, the spatial and temporal availability of water resources, or in general the water balance, can be significantly altered with any changes in temperature.

Water and food security are the key challenges under climate change as both are highly vulnerable to continuously changing climatic patterns. Africa which is one of the world's driest continents is facing a very severe water crisis. Over 90% of Sub-Saharan Africa agriculture is rain-fed, and mainly under smallholder management (Batino and Waswa, 2011). For instance, in Sub-Saharan Africa) by 2050 the rainfall could drop by 10%, which would reduce drainage by 17% (Anil K.M., 2014). Although most studies have been confined to modeling hydrological responses to climate change (Warburton et al. 2011), showed that land use and land cover plays a significant role in controlling hydrological responses. Additionally, stream flow is influenced not only by climate, but by numerous other human activities such as catchment land use changes, inter-basin water transfers, water abstractions, return flows or reservoir construction (Warburton and Schulze, 2005). Current scientific research shows that climate change will have major effects on precipitation, evapotranspiration, and runoff and ultimately on the nations water supply. The practical expression of climate change seems more visible through its effects. Nevertheless, these effects are widely spread at different levels of terrestrial and social systems (Sohoulande and Singh 2016). The rises of global temperature as the primary impact of climate change, and then derive different levels of impacts (Figure 1).

The aim of this review paper is to describe the brief impacts of climate change on soil and water resource and their future adaptation strategies

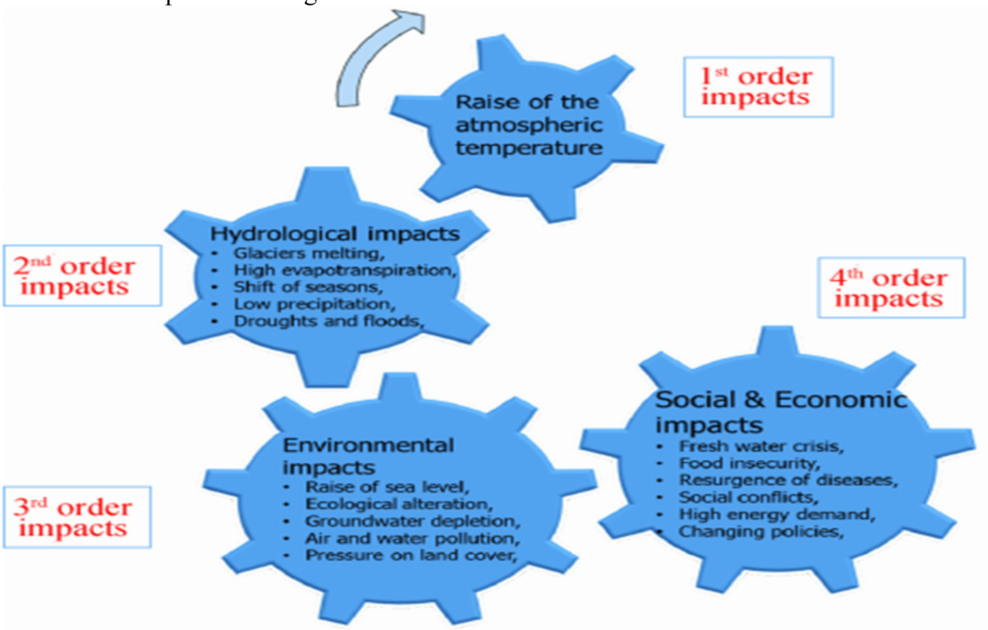

Figure 1: Hierarchy of the impacts of climate change focusing on the hydrologic framework (Sohoulande and Singh 2016). Here we target the rise of global temperature as the primary impact of climate change, and then we derive different levels of impacts.

The Hydrological Cycle and Climate Change

Hydrologic or water cycle describes a natural set of continuous and dynamic processes through which water masses in the form of liquid, vapor or solid, move, circulate and are stored within the earth system (IPCC, 2013). It is continuous circulation of water between ocean, atmosphere and land. The main components of hydrology cycle are the precipitation, evaporation, runoff, groundwater, and soil moisture, and it is liked with changes in atmospheric temperature and radiation balance (Figure 2). The water cycle is a key process upon which other cycles of the climate system operate. Water is transferred through physical processes like evapotranspiration, precipitation, infiltration and river runoff. It defines the sequence of transitions where the Earth's water (i.e., oceanic, cryospheric, and continental moisture) evaporates into and travels in the atmosphere, condenses to form clouds, returns to the earth surface as precipitation, runoff to the oceans as stream flow, and ultimately evaporates again.

The hydrologic cycle, often called water cycle, is one of the main components of the planetary system regulating human, animal and plant life. This cycle also forms the foundation of other cycles, such as carbon cycle, nitrogen cycle, etc. Therefore, the stability of water cycle is critical for the sustainability of every living thing. The stability of the hydrologic cycle is being threatened by climate change. The alteration of the water cycle is an alarming threat for the stability and sustainability of human societies and natural ecosystems (Hanjra and Qureshi, 2010). Rising global temperatures will lead to an intensification of the hydrological cycle, resulting in dryer dry seasons and wetter rainy seasons, and subsequently heightened risks of more extreme and frequent floods and drought. Changes in climate, with resultant increasing temperatures and changing rainfall patterns may alter hydrological responses (Kundzewicz et al., 2007).

Therefore, changes in the water cycle, which are consistent with the warming, observed over the past several decades, results in: Changes in precipitation patterns and intensity, Changes in the occurrence of drought, Widespread melting of snow and ice, Increasing atmospheric water vapor, Increasing evaporation, Increasing water temperatures, Changes in soil moisture and runoff and in general change in water resources availability.

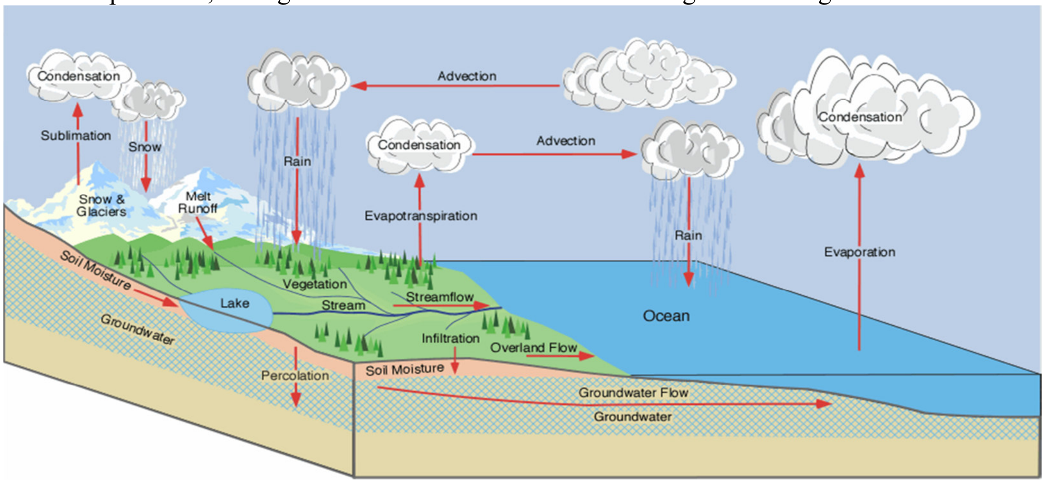

Figure 2: Hydrologic cycle

Climate Change and Water Resources

Increases in temperature and reduced rainfall for instance cause reduced stream flows in major catchments, reduced recharge of groundwater, reduced inflows to water storages, or intensified droughts. Water resources are believed to be particularly vulnerable to increased temperature and alternations in precipitation patterns. Precipitation is the main driver of variability in the water balance over space and time. Changes in precipitation have very important implications for hydrology and water resources. Climate change over the 21st century is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions (robust evidence, high agreement), intensifying competition for water among sectors (IPCC, 2014). Changes in surface runoffs and groundwater flows in shallow aquifers is part of the hydrological processes that can be linked to climate variability, with implications for permanent and seasonal water bodies such as lakes and reservoirs. There is evidence of a broadly coherent pattern of change in annual runoff at the global scale, with some regions, particularly at high altitudes, experiencing an increase (Tao et al., 2003a, b; Hyvarinen, 2003; Walter et al., 2004) while others experience a decrease, for example in parts of Africa (Milly et al., 2005). While lake levels in other parts of the world have risen (e.g. in Mongolia and China) in response to increased snow and ice melt, lake levels in Africa have declined due to the combined effects of drought, warming and human activities. The global ocean will continue to warm during the 21st century. The strongest ocean warming is projected for the surface in tropical and Northern Hemisphere subtropical regions (IPCC, 2014).

Climate change leading to increased surface temperatures, melting of snow and glaciers, rise in sea level and an increase in extreme weather events such as droughts and floods, can significantly affect water resources. The potential effects of climate change on water resources in Africa include: flooding, drought, change in the frequency and distribution of rainfall, drying-up of rivers, melting of glaciers, receding of water bodies, landslides, and cyclones among others (Kevin CU and Nicholas O., 2010). In relation to water quantities, changes in temperatures, precipitation patterns, including intensity and seasonality of rain events, snow cover, erosion etc., will have various impacts on river flows, groundwater recharge, lake levels, soil moisture, timing of and vulnerability to extreme events, and more globally impact water resource. With respect to water supply, it is very likely that the costs of climate change will outweigh the benefits globally. One reason is that precipitation variability is very likely to increase, and more frequent floods and droughts are anticipated.

In most developing countries, especially African, there are urgent needs to understand the dynamics of local climate and make predictions to respond to climate variability and change. The economies of most developing countries depend heavily on climate-sensitive sectors such as water, agriculture, fisheries, energy and tourism, climate change therefore poses a serious challenge to social and economic development in developing countries (Munang et al., 2013).

Climate Change and Soil resources

Soils are now recognized to be in the 'front line' of global environmental change and we need to be able to predict how they will respond to changing climate, vegetation, erosion and pollution (FAO and ITPS, 2015). This requires a better understanding of the role of soils in the Earth system to ensure that they continue to provide for humanity and the natural world (Schmidt et al., 2011). Soils play a fundamental role in the maintenance of a climate favorable to life. A range of soil processes helps regulate climate, including the thermal and moisture balance, greenhouse gases (H2O, CO2, CH4 and N2O) and particulates in the atmosphere. Soils can also adversely impact the maintenance of air quality (FAO and ITPS, 2015). For instance, Land-use conversions and drainage of organic soils for cultivation are responsible for about 10% of all greenhouse gas emissions (FAO, 2014).

Soils are both affected by and contribute to climate change (FAO, 2014). The carbon that is fixed by plants is transferred to the soil via dead plant matter including dead roots and leaves. This dead organic matter creates a substrate which soil micro-organisms respire back to the atmosphere as carbon dioxide or methane depending on the availability of oxygen in the soil. Some of the carbon compounds are easily digested and respired by the microbes, resulting in a relatively short residence time. Others become chemically and/or physically stabilized in soils and have longer residence times. Soil organic carbon can also be thermally decomposed during fire events and returned to the atmosphere as carbon dioxide. Remaining charred material can persist in soils for long periods (Lehmann et al., 2015). Soils can be a carbon source and sink. Therefore, soils contribute to the regulation of the carbon cycle and its consequent effects on climate change. Changes in land use constitute the driving force that determines the soil's role as a source or as a sink of carbon. Many of the impacts of climate change on soils are influenced by soil organic carbon. In mineral soils, the approximate relationship between organic matter and soil organic carbon is 1.724 x % organic carbon = % organic matter. Temperature increase would cause a higher decomposition rate of the OC. Increased drought would have the opposite effect. As shown in the figure 3, it is estimated that Ethiopia loses more than 1.5 billion tons of fertile soil each year through heavy rain and flooding; this lost soil could have increased the country's crop production by an estimated 1.5 million tons (Tamene and Vlek, 2008).

Figure 3: Active land degradation as a result of soil erosion in Northern Ethiopia.

Soils Carbon Sequestration

Carbon and nitrogen are major components of soil organic matter. Soils are integral parts of several global nutrient cycles. The two that are the most important from the perspective of soils and climate change interactions are the carbon and nitrogen cycles because carbon and nitrogen are important components of soil organic matter (Brady and Weil, 2008) and because carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) are the most important of the long-lived greenhouse gases (Hansen et al., 2007). Climate change and its hydrological consequences may result in the significant modification of soil conditions. Defining soil health in relation to climate change should consider the impacts of a range of predicted global change drivers such as rising atmospheric carb on dioxide(CO2) levels, elevated temperature, altered precipitation and atmospheric nitrogen deposition, on soil chemical, physical and biological functions (Frenchet al. 2009). Soil is the second largest carbon store, or 'sink', after the oceans.

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 (Brinkman and Sombroek, 1996). Indirect effects of climate change on soils through CO2-induced increases in growth rates or water-use efficiencies, through sea-level rise, through climate-induced decrease or increase in vegetative cover, or a change in human influence on soils because of the changes in options for the farmer, for example, may well each be greater than direct effects on soils of higher temperatures or greater rainfall variability and larger or smaller rainfall totals. Higher temperatures may lead to more vegetation growth and more carbon stored in the soil.

However, higher temperatures could also increase decomposition and mineralization of the organic matter in the soil, reducing organic carbon content. In contrary, the carbon-containing organic matter in stable peat lands is prevented from decomposing due to the low levels of oxygen in the water. If such areas dry out, the organic matter can quickly break down, releasing carbon dioxide (CO2) into the atmosphere. There is a strong scientific consensus that the soil moisture content is being affected by rising temperatures and changes in precipitation patterns. The increasing concentration of carbon dioxide in our atmosphere may cause the microbes in the soil to work faster to break down organic matter, potentially releasing even more carbon dioxide. Organic carbon in turn has a significant influence on soil structure, soil fertility, microbial processes and populations in the soil, and other important soil properties. Increased atmospheric CO2 would lead to increased plant productivity (growth) coupled with increased carbon sequestration by soil, with the implication that increased plant growth and the soil–plant system would help offset increasing atmospheric CO2 levels (Hätenschwiler et al., 2002). Increased temperature is likely to have a negative effect on carbon allocation to the soil, leading to reductions in soil organic carbon and creating a positive feedback in the global carbon cycle as global temperature rise (Gorissen et al., 2004; Wan et al., 2011). Atmospheric CO2 is utilized during photosynthesis and transformed into plant biomass (Brevik, 2012). As the biomass enters the soil and decays, some of it is transferred into soil organic matter and some returns to the atmosphere as CO2. Soil organic matter also decays and releases CO2 to the atmosphere. If more plant biomass is added to the soil than decays, the total amount of soil organic matter increases, resulting in carbon sequestration (Figure 4).

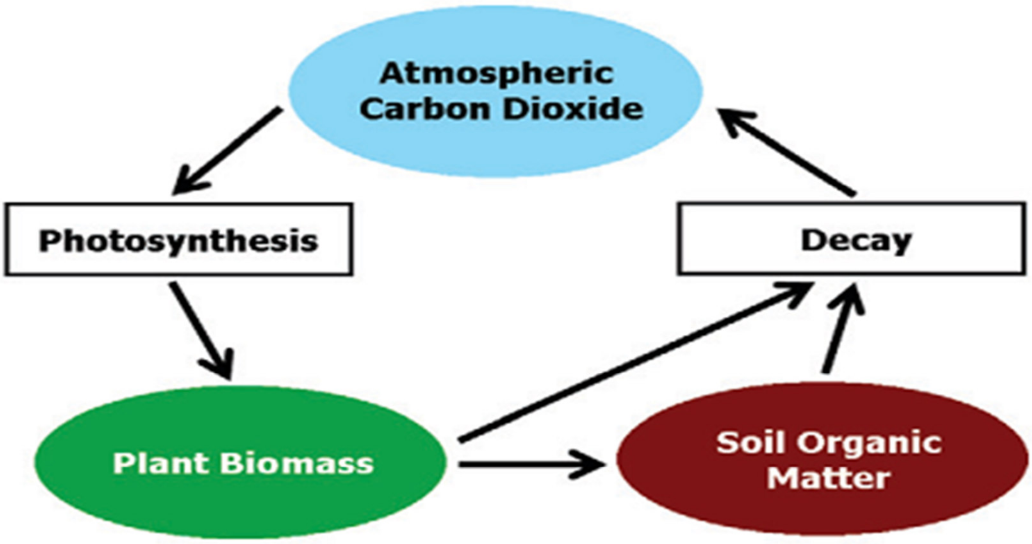

Figure 4. The concept of carbon sequestration by soils

Major impacts of climate change on soil processes and Properties

Climate is one of the most important factors affecting the formation of soil with important implications for their development, use and management perspective with reference to soil structure, stability, and topsoil water holding capacity, nutrient availability and erosion. Soil properties that could be modified by climate change would be organic carbon content, characteristics of soil biota, moisture and temperature regimes and processes such as erosion, salinization or physical, chemical or biological fertility. The climatic parameters driving these changes would be temperature, rainfall (quantity, intensity and temporal distribution), together with atmospheric chemistry, especially carbon dioxide and nitrogen and sulphur compounds due to the increase in temperature and drought.

Soil Formation

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. 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. Changes in external factors of soil formation (temperatures and precipitation) will lead to transformation of internal factors (energy, hydrological, biological). The climate change will increase energy of destruction of soil minerals resulting in simplification of mineral matrix due to accumulation of minerals tolerant to weathering. It will lead loss of soil function for fertility maintenance and greater dependence of on mineral fertilizers (Pareek, 2017). Soil development is broadly controlled by three main factors i.e. climate, parent material and vegetation type. The effects of climate change on soil development are expected mainly through alteration in soil moisture conditions and increase in soil temperature and CO2 levels. Among various factors controlling the process of soil development, climate plays a major role in weathering of rocks and minerals. The variables of climate change particularly temperature and rainfall dictate various stages of weathering of rocks and minerals (parent material) resulting in chemical and mineralogical changes in soil forming rocks.

Water is very essential for chemical weathering to take place and hence, an increase in rainfall accelerates weathering (Pareek, 2017). The same types of primary minerals give rise to different secondary minerals when the conditions of weathering differ. Thus, similar rock types undergoing weathering in different climatic conditions could give rise to distinct soil profiles.

Table 1: Summary of expected effects of rain fall variability on soil processes (Pareek, 2017).

Increasing Rainfall	**Increase in soil moisture or soil wetness**
	Enhanced surface runoff and erosion
	Increase in soil organic matter
	Nutrient leaching
	Increased reduction of Fe and nitrates
	Increased volatilization loss of nitrogen
	Increase in productivity in arid regions
Reduction in Rainfall	**Reduction in soil organic matter**
	Soil salinization
	Reduction in nutrient availability

Soil Fertility and Nutrient Availability

A new European study has found that soil carbon loss is more sensitive to climate change compared to carbon taken up by plants. In drier regions, soil carbon loss decreased but in wetter regions soil carbon loss increased. This could result in a positive feedback to the atmosphere leading to an additional increase of atmospheric CO2 levels (Sabine et al., 2017). The authors showed that soil carbon loss is most responsive to change in soil water. Soil water plays a critical role in wet soils where water logging limits decomposition processes by soil biota resulting in a build-up of soil carbon as peat. Drying of the soil removes this limitation resulting in soil carbon loss.

Soils are intricately linked to the climate system through the nitrogen, carbon, and hydrologic cycles. Because of this, change in climate will have an effect on soil processes and properties. Soil organic matter levels react to changes in the carbon and nitrogen cycles will influence the ability of soils to support crop growth, which has significant ramifications for food security. Therefore, further study of soil-climate interactions in a changing world is critical to addressing future food security concerns Nitrogen cycle (Brevik, 2013). Soils are integral parts of several global nutrient cycles. The two that are the most important from the perspective of soils and climate change interactions are the carbon and nitrogen cycles because C and N are important components of soil organic matter (Brady and Weil, 2008) and because carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) are the most important of the long-lived greenhouse gases (Hansen et al., 2007).

The global carbon and nitrogen cycles were in balance with inputs approximately equaling outputs prior to the industrial revolution when low populations and levels of technology minimized the anthropogenic generation of greenhouse gases, but the burning of fossil fuels, tilling of soil, and other human activities have altered the natural balance such that we are now releasing more carbon and nitrogen into the atmosphere each year than is taken up by global sinks (Pierzynski, 2009). Human management of soils can have a profound impact on the balance of carbon and nitrogen gas emissions from those soils, and therefore influences global climate change (Brevik, 2013).

Carbon and Nitrogen cycles

Changes in temperature and rainfall patterns can have a great impact on the organic matter and processes that take place in our soils, as well as the plants and crops that grow from them (FAO, 2014). According to Brevik, (2013), the Earth's climate system is changing due to changing levels of greenhouse gases in the atmosphere; the most important of these gases are carbon and nitrogen based. Because soils are part of the carbon and nitrogen cycles and carbon and nitrogen are both important components of soil organic matter, the organic matter content of soils will be influenced by climate change.

Changes in average temperatures and in precipitation patterns will also influence soil organic matter. This in turn will affect important soil properties such as aggregate formation and stability, water holding capacity, cation exchange capacity, and soil nutrient content. Exactly how soil organic matter will be influenced by climate change involves highly complex and interconnected systems that make it difficult to isolate a single variable, such as temperature or precipitation patterns, and reach meaningful conclusions about how a change in that single variable affects the system being studied. However, we do know that there is the possibility that soils could contribute increasing amounts of greenhouse gases to the atmosphere and lose their ability to act as a sink for C as global temperatures increase. Organic carbon cycling models and studies of climatic transects suggest a decrease in soil organic carbon. As a consequence, there is the chance we will see negative impacts on physical and chemical properties of our soils that are essential for the production of food and fiber products.

Carbon and nitrogen are major components of soil organic matter (Brady, 2008). Organic matter is important for many soil properties, including structure formation and maintenance, water holding capacity, cation exchange capacity, and for the supply of nutrients to the soil ecosystem (Brevik, 2009; 2013). Soils with an adequate amount of organic matter tend to be more productive than soils that are depleted in organic matter (Brevik, 2009), therefore, one of the biggest questions concerning climate change and its effects on soil processes and properties involve how potential changes in the carbon and nitrogen cycles will influence soils (Figure 5). At present, our understanding of how changes in climate will influence the carbon and nitrogen cycles is incomplete; meaning additional research into these questions is needed.

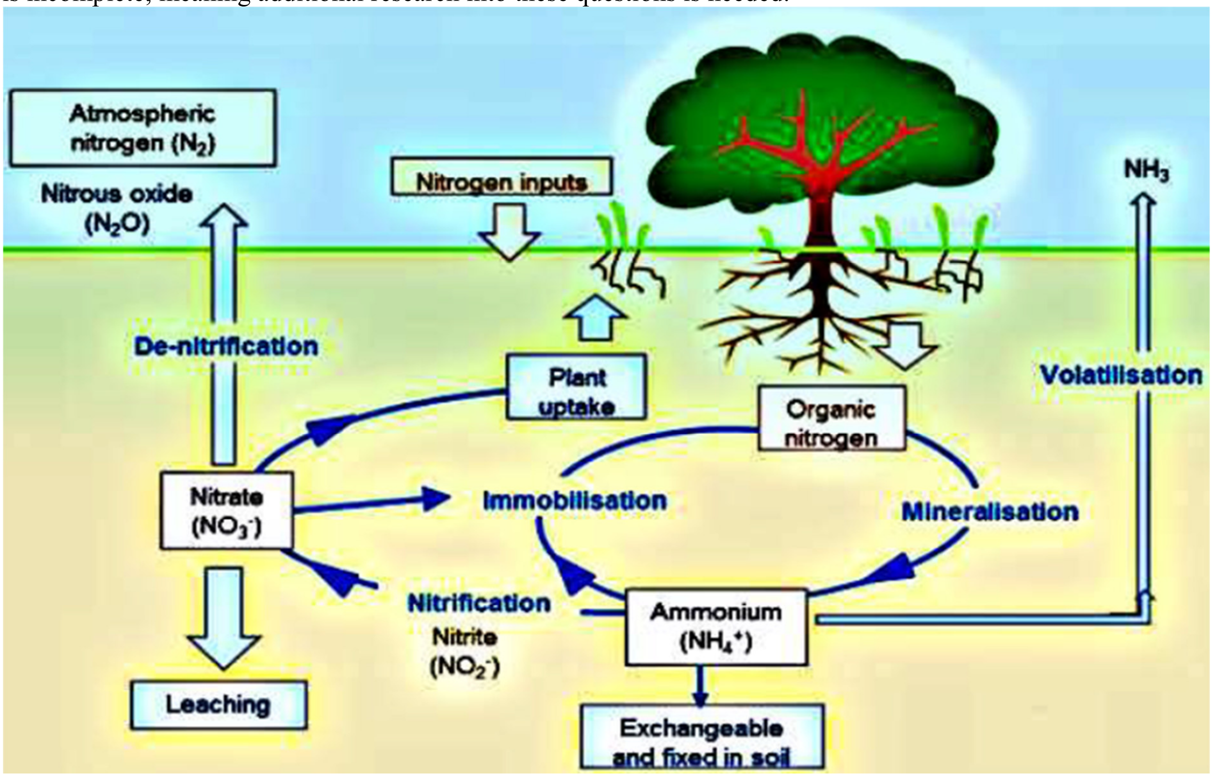

Figure 5: Nitrogen cycle and climate change

Summary

Water is involved in all components of the climate system: the atmosphere, hydrosphere, cryosphere, land surface and biosphere. The dynamics of the water cycle are one of the key variables that determine the distribution and productivity of ecosystems. Changes in global climate will have significant impact on local, regional and global hydrologic regimes, which may in turn impact ecological, economic and social systems. Water resources are a main component of natural systems that might be affected by climate change. The effect of climate change on the precipitation, stream flows, and groundwater recharge components which would affect directly over the water resources availability under climate stress. The Impact of climate change on water availability will depend on changes in precipitation (including changes in the total amount, form and seasonal timing of precipitation). In areas where precipitation increases sufficiently, net water supplies might not be affected or they might even increase. If the precipitation remains the same or decreases though, net water supplies would decrease. Climate change will affect water resources through its impact on the quantity, variability, timing, form, and intensity of precipitation.

Soils are intricately linked to the atmospheric/climate system through the carbon, nitrogen, and hydrologic cycles. Altered climate will, therefore, have an effect on soil processes and properties. Changes in average temperatures and in precipitation patterns will also influence soil organic matter. This in turn will affect important soil properties such as aggregate formation and stability, water holding capacity, cation exchange capacity, and soil nutrient content.

To minimize the impact of climate change on soil and water resources it is necessary to understand and evaluate the vulnerability of soil and water resources to global warming impacts. After understanding these impacts only policies and strategies should be formed and implemented. All efforts should be made to present future impacts by reducing greenhouse gas emission. There are two ways to manage the risks posed by climate change: mitigation of GHGs to slow or reverse the pace of climate change, and adaptation to climate impacts to minimize their effects. Examples of mitigation include measures such as energy efficiency, promotion of renewable energy sources, and carbon trading.

This review paper summarizes the following measures/adaptation options to minimize the impact of climate change on soil and water resources.

- Manage water resources in a changing climate by implementing Integrated Water Resources Management approaches in highly vulnerable basins.
- Promote soil and water conservation practices.
- Implement water conservation and efficiency programs to reduce the amount of water needed for irrigation, municipal, and industrial users and to improve basin-wide water supply.
- Most vulnerable to climate change regions should adapt strategies to manage climate change risk.
- Development in irrigation infrastructure should be carried out in all vulnerable countries to cope with climate change risk.
- Groundwater development such as rainwater harvesting, watershed management and rainwater should be implemented on a large scale in all vulnerable areas.
- Watershed development and upgrading rain fed agriculture through rainwater harvesting.
- Development of watershed based integrated water resource management approach
- Constructing water storage structures to store excess water flowing during rainy season so as to use it for dry season.
- Awareness creating among the community of the future climate change in the watershed area and development of ground water and effective rainwater harvesting technologies.

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