UNIT 5 SOIL ECOSYSTEM

Structure

5.1 INTRODUCTION

Since the industrial revolution, anthropogenic activities such as industrial, economic and land-use and population growth have contributed substantially to climate change by adding CO_2 and other heat-trapping gases to the atmosphere. CO_2 remained the major anthropogenic GHG accounting for 76% (38±3.8 $GtCO_2eq$/year) of total anthropogenic GHG emissions in 2010. 16% (7.8±1.6 $GtCO_2eq$/year) come from CH_4, 6.2% (3.1±1.9 $GtCO_2eq$/year) from N_2O, and 2.0% (1.0±0.2 $GtCO_2eq$/year) from fluorinated gases. The IPCC estimated that global mean surface temperature could rise over 6°C by 2100. The atmospheric concentration of CO_2 has increased by 42% from 280 ppm in the preindustrial era to 400 ppm in 2014. Increase in the concentration of CO_2 and other GHGs (CH_4, N_2O) has increased the global mean temperature by 0.85°C (0.65±1.06°) over the twentieth century (IPCC 2014).

Continued emission of GHGs will cause further warming of the atmosphere; changes in entire components of the climate system; and severely affect the livelihood, and cause pervasive and irreversible impacts on people and ecosystems (terrestrial and aquatic ecosystem). Climate change will also amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally more significant for disadvantaged people and communities in countries at all levels of development. The appearance of abnormal precipitation and extremes will modify climate change impacts and creates adverse effects on soil, plants and human and animals. Climate change is also assumed to enhance the severity and frequency of floods, wildfire, glaciers melting, dry spell, spreading of new disease, crop shifting, famine and insect-pest attacks (Lal, 2011). This unit will give you an overview of soil interactions with environmental components; soil as a source of greenhouse gases emissions; climate change impacts on soil carbon and nitrogen dynamics; and also the impacts of climate change on evapotranspiration, and soil salinization.

5.2 OBJECTIVES

After studying this unit, you should be able to:

- identify the interactions between soil and components of environment;
- explain greenhouse gases emissions from soil;
- explain the climate change impacts on soil carbon and nitrogen dynamics; and
- explain the impacts of climate change on evapotranspiration, and soil salinization.

5.3 SOIL AND ITS INTERACTIONS WITH THE ENVIRONMENT

The soil is an integral part of the environment. The lithosphere, hydrosphere, atmosphere, and biosphere are environmental compartments that overlap and are intimately associated in the ecosystem. Therefore, what happens in soil should have a profound impact on not only soil quality but also ecosystem health. The soil is a dynamic system in which continuous interaction takes place between soil minerals, organic matter, and organisms. Each of these three major soil components influences the physicochemical and biological properties of terrestrial systems. Interactions between the mineral, organic and biological factors have an enormous impact on terrestrial processes critical to environmental quality and ecosystem health; they control the cycling and bioavailability of nutrients and xenobiotic substances in the environment through physical, chemical, biochemical and biological processes Soil and its interactions with the environment components is presented in Fig. 5.1.

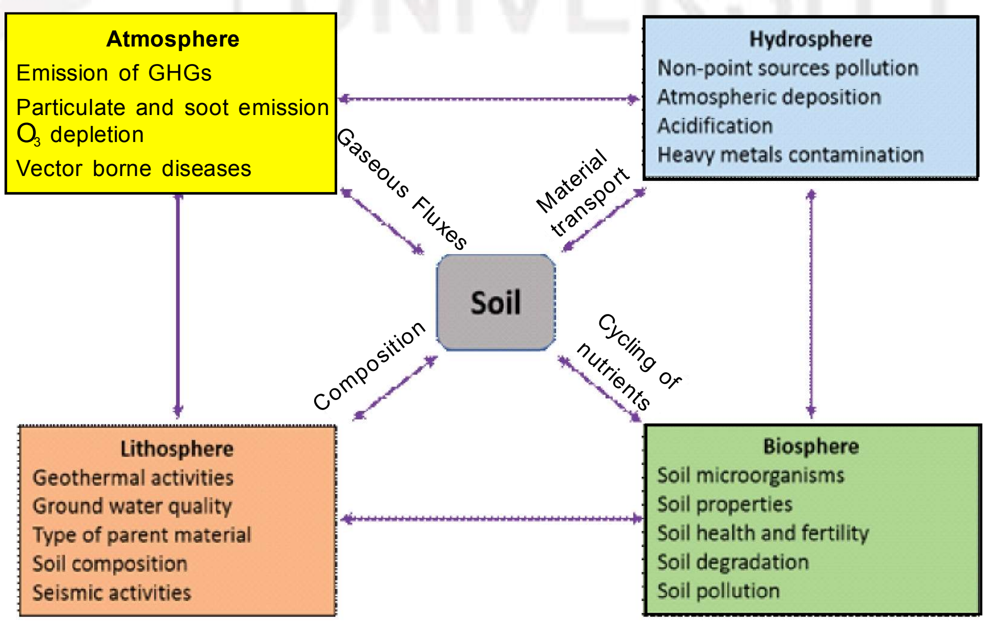

Fig. 5.1 : Soil and its interactions with the environment components (Modified from Lal, 2011)

Changing climate is a growing consensus among the scientific as well as the farming community in the 21st century. As per the World Meteorological Organization (WMO), there are several natural and human-made mechanisms affecting the global energy balance and force changes in Earth's climate. The radiatively active gases, viz. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), popularly known as the 'greenhouse gases' (GHGs) are one such mechanism. GHGs absorb and emit some of the outgoing energy radiated from Earth's surface, causing that heat to be retained in the lower atmosphere. Consequently, the average temperature of Earth's surface atmosphere is increasing, a phenomenon which is commonly known as global warming.

The climate change and its variations are driven by both natural as well as anthropogenic factors and that are separately emphasized in definitions of climate change stated by Intergovernmental Panel on Climate Change (IPCC) and United Nations Framework Convention on Climate Change (UNFCCC). According to IPCC, climate change can be defined as a change in climate state that can be identified by changes in the mean and/or variability of its properties, that persists for an extended period typically decades or longer, whether due to natural variability or as a result of human activity. Moreover, UNFCC, defined as a change of climate that is attributed directly/indirectly to anthropogenic activity that alters the global atmospheric composition and that is in addition to natural climate variability observed over comparable periods (UNFCCC, 2011).

The global environmental consequences of climate change will pose severe effects on terrestrial ecosystems, especially for agriculture and forestry. The apparent connection between soil health and climate is moderated through sink and source of carbonaceous (CO_2, CH_4, soot), nitrogenous (N_2O, NO_x), and other organic and inorganic compounds. In agriculture, the soil is an essential component that supports crop production, a platform for biogeochemical processes, source or a sink for GHGs, buffer medium for chemical reactions, microbial diversity and life on the earth (Fig. 5.1). Soil organic matter (SOM) is an integral part of soil to sustain soil fertility and health and, also provide a resilient capacity to soil. The increasing SOM can halt the rising concentration of GHG mainly CO_2 in the atmosphere and improve soil structure, and reducing soil erosion and land degradation processes. A healthy soil improves plant yield, promotes plant, animal and human strength, maintains water and air quality, supports a diversity of soil microbes, and resists stresses of human impact and climatic perturbations, so resists environmental degradation. However, climate change can adversely affect the vital processes of soil like physical, chemical and biological functions as shown in Table 5.1 (Lal, 2011).

Table 5.1. Climate change effects on soil processes (Pareek, 2017).

S.N.	Climatic variable	Effects
1.	Increasing temperature	Loss in SOC
		Decrease in labile pool of SOM
		Decrease in moisture content
		Increase in mineralization rate
		Soil structure destruction

2.	Increasing CO_2 level	Loss of SOM
		Increase in WUE
		More availability of carbon to soil microbes
		Nutrient cycling acceleration
		Increase in soil respiration rate
3.	Fluctuations in rainfall (Increase/decrease/scattered)	Increase in soil moisture content
		Surface runoff and erosion increased
		Nutrient leaching acceleration
		Increased reduction of Fe and nitrates
		Increased volatilization loss
		Increase in productivity in arid zones
		Reduction in SOM
		Soil salinization increased
		Reduction in nutrient availability

5.4 CLIMATE CHANGE IMPACTS ON SOIL CARBON AND NITROGEN DYNAMICS

Physical, chemical and biological properties of soil provide information associated with water, air, temperature, microbial activities, and soil reactions, as well as conditions influencing germination, root growth and erosion processes. Several soil physical properties form the basis of other chemical and biological processes, which may be further directed by climate, landscape position, and land use. The carbon and nitrogen dynamics of soil are highlighted as potential soil health factors, and critical soil indicators about climate change include mineralization, volatilization, microbial decomposition, salinization, evapotranspiration, enhanced greenhouse gases emissions, which are discussed below (Fig. 5.2).

The organic matter content in the soil is a sign of organic matter quality and soil health, acting as nutrient agent for microbes during the nutrient cycling process under climate change conditions (Gregorich et al. 1994). SOM drives the soil functions, and decreases in SOM can lead to a reduction in fertility and microbial biodiversity, as well as a loss of soil structure, followed by decreased WHC, increase in soil erosion (Weil and Magdoff 2004). At the farm level, land use change and management practices that lead to building up of organic matter in soil will help absorb CO_2 from the atmosphere, thus mitigating global warming and climate change abnormalities. By increasing soil moisture and water storage, organic matter can perform an essential role in the mitigation of flooding impacts following extreme rainfall events, while saving water in the event of droughts thus increasing soil resilience.

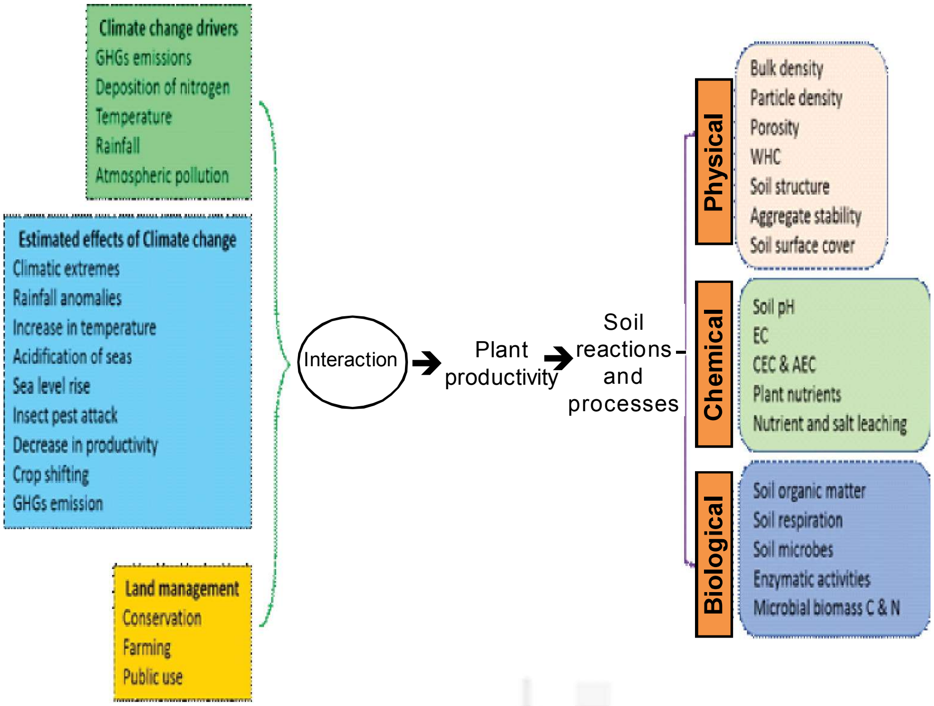

Fig. 5.2 : The schematic link between soil properties and climate change (Modified from French et al., 2009; Lal, 2011)

Microbial biomass, the living segment of SOM, is regarded as the common labile C pool in soils and a sensitive indicator of changes in soil quality, with links to soil nutrient and energy dynamics due to climate change (Haynes 2008; Saha and Mandal 2009). The recent investigations are showing that a significant decrease in the soil microbial biomass during long-term simulated climatic warming experiments (Rinnan et al. 2007). Soil organic carbon (SOC) decomposition is a microbial and enzymatic process, and the temperature dependence of SOC decomposition follows the Arrhenius equation, that is:

$$k = a\ \exp^{-Ea/RT}$$

Where k-reaction rate is constant, a-frequency factor, Ea-activation energy, R -gas constant (8.314 J K^{-1} mol^{-1}) and T-temperature (K) (Arrhenius 1889).

The temperature dependence of SOC decomposition has also been described by Q_{10} based functions, which is the factor by which the reaction rate increases with every 10 degrees rise in temperature (Table 5.2) (Davidson et al. 2006; Kirschbaum, 1995, 2000).

Table 5.2. Likely changes in soil organic carbon (C) stocks in major pools in a simulated upland soil and a permafrost soil in response to global warming by 2100 (modified from Dalal et al., 2011; Davidson and Janssens, 2006)

Organic C pools and temperature-sensitive ecosystems	Organic C Stock (Gt C)	Turnover Time (years)	Potential loss by 2100 (Gt C)	References
Upland soil (litter layer)	200	6	30	Jones et al. (2005)
Labile pool	20	6	3	Jones et al. (2005)
Slow pool	700	18	40	Jones et al. (2005)
Recalcitrant pool	100	1000	0.1	Jones et al. (2005)
Permafrost (3 m depth)	400	4	100	Gruber et al. (2004)

Deposition of atmospheric nitrogen ranges from 1 to >20 kg N ha^{-1} $year^{-1}$ (Galloway et al. 2004; Phoenix et al. 2006), with primary deposition (>10 kg N ha^{-1} $year^{-1}$) happening in populated regions of North America, Western Europe, South Asia and East Asia (Galloway et al. 2004). The extra nitrogen provided through atmospheric deposition can spur plant growth and hence increases C input as well as adds to soil N supply. The additional deposited N supply not only improves the result of elevated CO_2 concentration on SOC, it may also slow the rate of organic matter decomposition (Pepper et al. 2007).

Carbon stocks in the terrestrial ecosystem have been changed by growing atmospheric CO_2 concentration and N deposition, as well as by changing the land use pattern (Matson et al. 2002). In 2005, agriculture considered for an estimated emission of 5.1-6.1 Gt CO_2-eq $year^{-1}$, which is 10–12% of total global anthropogenic emissions of GHGs (Smith et al. 2007). The N-limited systems initially hold the deposited N by using it for plant and microbial growth as well as via accumulation in plant biomass and soil organic matter. Though, when inputs of N found to exceed the biotic needs within the ecosystem, the excess N can be possibly lost via leaching and gaseous emissions and triggers climate change (Matson et al. 2002). The induced N addition can have a deleterious impact on the soil through acidification and a consequential reduction in plant and microbial biodiversity (Galloway et al. 2003). During the acidification process, soils release base cations (Ca^{+2} and Mg^{+2}), neutralizing the development in acidity. Though, over time and with sustained enhancement of N, the base cations can be consumed, at which time Al^{3+} is released from soil minerals, often approaching towards toxic levels. Soil acidification influences to reduce microbial N immobilization (Venterea et al. 2004).

Check Your Progress 1

Note: a) Use the space given below for your answers.

b) Check your answers with those given at the end of the unit

1. What are the effects of increase in surface air temperature on soil?

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2. What are the potential impacts of increasing atmospheric carbon dioxide concentration on the soil environment?

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3. What are the significance of soil organic matter?

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5.5 GREENHOUSE GASES EMISSION FROM SOIL

Climate change is global phenomena and happening continuously since the earth came into existence. Climate change has become a significant scientific and political concern during the last decade. The soil appears to be more relevant for human societies than ever before to meet the global food requirements for the increasing population from limited soil resources. Climate change is predicted to have obvious consequences on agriculture through direct and indirect effects on crops, soils, livestock, and pests. Though climate change is a slow process including comparatively small changes in precipitation and temperature over a long time, these slow changes in climate influence the several soil processes. The impact of climate change on soils are expected mainly through a change in soil moisture content and fluctuations in soil temperature and CO_2 levels as a consequence of adverse climatic effects. The principal effect of climate change is expected through emission of GHGs especially CO_2, CH_4 and N_2O, and increase in temperature (Pareek, 2017).

Soil microbes have significant roles in climate change as well as in carbon and nitrogen dynamics in soil. The mitigation roles link to the capacity of microorganisms such as bacteria, algae, fungi, and archaea to create and utilize all the GHGs, i.e., N_2O, CH_4, and CO_2. The biogeochemical processes are cyclic, dynamic and adaptive and are regulated by several edaphic and climatic factors such as ambient and soil temperature, moisture content and management strategies (Fig. 5.3) (Mele, 2011). The soil microbes are likely to be influenced directly like physiological stress and adaptation responses and indirectly via habitat modification by global change scenarios. These climatic scenarios involve elevated temperature (1.4-5.8^oC by 2100), elevated atmospheric CO_2 (540 and 970ppm by 2100), elevated atmospheric N (316ppb in 2000) and fluctuating CH_4 concentrations (700ppb in 1,750 to 1,775ppb in 2005), and precipitation changes by an average of 20% on current levels (Solomon et al. 2007).

Human-induced change of the biogeochemical cycles is the most significant environmental challenge, particularly for C and N cycling (Mele, 2011). These cycles are highly interdependent and involved explicitly in greenhouse gas emissions into the atmosphere. Nitrous oxide (N_2O) and nitric oxide (NO) both are major GHGs that are generated from the plant and organic nitrogen by microbes which are converted into nitrogen gases, N_2O and N_2, and intermediator NO. There are two highly linked, microbial processes that produce N_2O and NO are nitrification and denitrification. Nitrous oxide is released from soil during the processes of nitrification and denitrification. Nitrification is the microbial oxidation of NH_4^+ to NO_3^- in the soil. Although the nitrification process is a key measure in the conversion of ammonia nitrogen into its gaseous forms, this process is less connected to N_2O emissions. Denitrification includes the reduction of NO_3 to NO, N_2O, and N_2 under anaerobic conditions of the soil (Green et al. 2010).

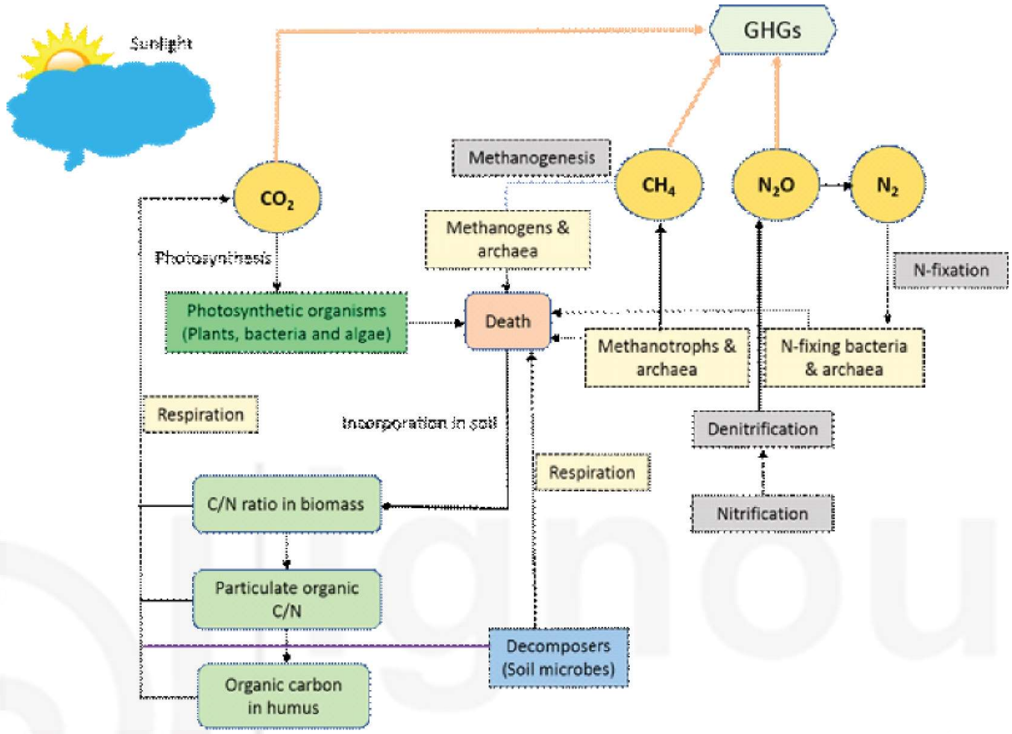

Fig. 5.3 : Schematic illustration of microbial carbon and nitrogen cycles with microbial capture and loss pathways linked with the emission of GHGs (modified from Mele, 2011)

Globally, the SOC pool is expected to be ~$1{,}395\times10^{15}$g (Post et al. 1982), and accumulation is regulated mainly by net primary productivity (NPP) while losses are mainly a function of the biological stability of the several chemical forms such as cellulose, tannins, lignin, starches, sugars and the gases (CO_2 and CH_4). The decomposition of organic carbon in soil and the generation of CO_2 during aerobic respiration are governed by the heterotrophic microbial community (Paul, 2007). The production of CH_4 in the comparatively more complicated microbial process governed by methanogens is also a respiration process that uses CO_2 and other forms of C instead of oxygen. CH_4 has 25 times more global warming potential than carbon dioxide (IPCC, 2007) and thus even at lower atmospheric concentrations provides about half the radiative climate forcing of CO_2 (Beerling et al. 2009). CH_4 is produced by methanogens and consumed by methanotrophs in the soil and ocean sediment at particular climatic conditions. CH_4 can be produced by both acetotrophic and hydrogenotrophic methanogens, and variations in environmental situations influence the structure of these communities (Demirel and Scherer 2008).

Climate is a principal factor in the growth and development of plant, and animals. The severe climate events and unsustainable land use and management, such as degradation of forest lands and intensive tillage operations in croplands, have been threatening soil fertility and the health of the surrounding environment. These outcomes, rather than turning soil into a sink of gases, make soil a source of GHG emissions, thus deteriorating the physical, chemical and biological components of soil quality. Holistically, under the nexus of climate change scenario and agricultural systems, sustainable management practices play a significant role in resilience to climate change. Such as conservation agriculture practice, i.e., minimal soil disturbance, plant and soil microbe's biodiversity, soil cover and careful integration of livestock into farming systems that build SOM and SOC could help improve soil resilience to climate change via fulfilling the soil health components.

5.6 IMPACTS OF CLIMATE CHANGE ON SOIL SALINIZATION

Salt is necessary for cooking and food preparation, but much quantity of salts in the soil can destroy the crops and render fields useless. Soil salinization in irrigated and rainfed areas is a degradation process that wrecks both soil fertility and crop productivity. The main foreseen consequences of climate change will be denoted by higher and more variable in temperatures, precipitation patterns and a higher frequency of extreme events (Ashour and Al-Najar, 2012). Diminishing water resources linked with salinity intrusion into surface and subsurface water will pose menace to water security. Therefore, sensing the linking of surface and subsurface water is crucial in managing sustainable water resource utilization. Water scarcity and soil salinization globally will have a significant impact on food security (Teh and Koh, 2016). The consequence of global warming and climate change are ubiquitous but essential for arid areas that are most prone to soil salinization. Salt accumulation is considerably accelerated in the soils of Central Asia. The climatic factor (mainly precipitation) defines the way of salt redistribution in the soil profile. The winter and spring rainfall ensures more rapid carryover of readily soluble salts.

The climatic variations will expand the regions of saline soils mainly due to following reasons: firstly, the increasing temperature and aridity have a direct effect on salt movement and the salt balance of soils, and secondly, the indirect effect on salt dynamics by altering the land use pattern (Szabolcs, 1990). When sea levels rise, low-lying coastal regions are frequently being inundated with saltwater, continually contaminating the nearby soil. These salts can be scattered by rainfall, but climate change is also increasing the incidence and severity of extreme weather situations, including droughts and heat waves. This leads to more exhaustive use of groundwater for drinking and irrigation, which further drains the water table and allows even more salt to leach into the soil. Climate change factors affect soil salinity by rising ocean temperatures and warming the water. Investigators currently predicted that global mean sea levels would rise by at least 0.25 to 0.5m by 2100, even with higher decreases in GHG emissions. Globally, soil salinity will cause increased food prices and more food deficits and several farmers are also getting lower yields, which indicates less income.

5.7 IMPACTS OF CLIMATE CHANGE ON EVAPOTRANSPIRATION

Evapotranspiration (ET), one of the principal elements of the hydrologic cycle, is influenced by climate change. The climatic factors are changing over extended periods, which is an indication of climate change (IPCC, 2014). A change in the patterns of climatic factors due to climate change intends a variation in evapotranspiration rates (Helfer et al., 2012). Potential evaporation (ET_0) can be regarded as a measure of atmospheric evaporative demand and is a measure of the integrated effect of several meteorological factors, i.e., solar radiation, wind speed, ambient temperature, vapour pressure, and humidity (Dinpashoh et al., 2018). Atmospheric temperature is probably considered to be the most broadly used indicator of climatic change on both regional as well as global scales. As per the IPCC report (2013), over the past 100 years (1913–2012), global temperature has increased by 0.91 °C (Stocker et al. 2014) and it is expected to continue rising throughout the twenty-first century, modifying the hydrological cycle by altering both precipitation and evaporation (Huntington 2006). This could have significant influences on water quantity, quality and availability particularly in poor semiarid regions (Dastorani and Poormohammadi, 2012). Potential evapotranspiration (ET_0) is broadly recognized as a critical hydrological variable describing a substantial water loss from catchments. It is related to groundwater recharge, runoff, and water movements in soil, some critical kinds of hydrological processes (Zhang et al. 2011), and it can also be used to determine actual evapotranspiration (ETa), scheduled irrigation, and other management practices in the crop field (Xu and Li 2003). Drought situations will reasonably be increased due to climate change by raising potential evapotranspiration and growing crop water consumption in water-scarce regions (Thomas 2008). According to the forecasts of climate change models, ET_0 is supposed to increase over the coming years due to expected temperature acceleration (Liu et al., 2018; Goyal 2004).

Check Your Progress 2

Note: a) Use the space given below for your answers.

b) Check your answers with those given at the end of the unit

1. What are the influences of climate change on soil salinization?

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2. What is potential evapotranspiration? What are the impacts of climate change on evapotranspiration?

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5.8 LET US SUM UP

We have studied in this unit about the importance of soil in crop production. We have discussed in detail the potential impact of changing climate on soil carbon and nitrogen dynamics, and also on evapotranspiration and soil salinization.

5.9 KEYWORDS

Soil : Soil is natural body developed by natural forces acting on natural materials. It is usually differentiated into horizons from mineral and organic constituents of variable depth which differ from the parent material below in morphology, physical properties and constituents, chemical properties and composition and biological characteristics.

Soil Moisture : Water stored in or at the land surface and available for evapotranspiration.

Evapotranspiration : The combined process of evaporation from the Earth's surface and transpiration from vegetation.

Drought : A period of abnormally dry weather long enough to cause a serious hydrological imbalance.

5.10 SUGGESTED FURTHER READING/ REFERENCES

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5.11 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 1

1. The effects of increase in surface air temperature on soil include but not limited to increase in mineralization rate; decrease in labile pool of soil organic matter; loss in soil organic carbon; decrease in moisture content; and soil structure destruction.

2. The potential impacts of increasing atmospheric carbon dioxide concentration on the soil environment include acceleration of nutrient cycles; increase in soil respiration rate; and increased availability of carbon to soil microbes.

3. The organic matter content in the soil is a sign of organic matter quality and soil health, acting as nutrient agent for microbes during the nutrient cycling process under climate change conditions. By increasing soil moisture and water storage, organic matter can perform an essential role in the mitigation of flooding impacts following extreme rainfall events, while saving water in the event of droughts thus increasing soil resilience. At the farm level, land use change and management practices that aid in building up of organic matter in soil will help absorb CO_2 from the atmosphere, thus mitigating global warming and climate change abnormalities.

Check Your Progress 2

1. The climatic change and variability will expand the regions of saline soils due to following reasons: firstly, the increasing temperature and aridity have a direct effect on salt movement and the salt balance of soils, and secondly, the indirect effect on salt dynamics by altering the land use pattern. The rise in sea levels rise lead to inundation of low-lying coastal regions, and contamination of soil. Increasing temperature leads to more exhaustive use of groundwater for drinking and irrigation, which further drains the water table and allows even more salt to leach into the soil.

2. Potential evaporation (ET_0) can be regarded as a measure of atmospheric evaporative demand and is a measure of the integrated effect of several meteorological factors, i.e., solar radiation, wind speed, ambient temperature, vapour pressure, and humidity. Potential evapotranspiration (ET_0) is broadly recognized as a critical hydrological variable describing a substantial water loss from catchments. It is related to groundwater recharge, runoff, and water movements in soil, some critical kinds of hydrological processes. Drought situations will reasonably be increased due to climate change by raising potential evapotranspiration and growing crop water consumption in water-scarce regions.