15 Climate Change and Soil

Emissions of greenhouse gases have alarmingly increased in the past due to land use changes, cultivation, and burning fossil fuels. Concentrations of CO_2, CH_4, and N_2O in the atmosphere have increased by 37, 156, and 19% in the atmosphere, respectively, over 1750 values. Global temperature has risen by 0.75 °C since 1850 and projected temperature rise in the twenty-first century ranges from 1.8 to 4 °C. Sea level has risen in many places, arctic ice is melting, and permafrosts are in danger of thawing. Extreme events such as floods and droughts have become more frequent. Changing climate has a crucial role on ecosystems including soil. Soil contains a large stock (1.5×10^{18} g C) of stabilized carbon in the form of soil organic matter. Rising temperature may enhance decomposition of soil organic matter and might convert soil as a source of atmospheric CO_2. Soil management practices such as no-till or minimum till, using manures and composts, mulching, cover crops, reducing summer fallow, restoration of degraded lands, afforestation, and reforestation would significantly sequester carbon, reduce greenhouse gas emissions from the soil, and help to mitigate climate change and adapt to it.

15.1 Weather Is a Short-Term and Climate Is a Long-Term Phenomenon

The sky is cloudy; it is the weather of the place today. The sky remains always cloudy here; it is the climate of the area. So, weather is a day-to-day event of the atmosphere, and climate is a general average of the conditions of precipitation, temperature, air pressure, humidity, sunshine, cloudiness, and winds of a region over a long period of time. Weather varies over short distances and within a short time such as between the morning and the evening, whereas climate remains the same in a large area over a long period of time. In fact, climate is the composite of generally prevailing weather conditions of a region with all its variations from time to time. So, the weather is what is happening to the atmosphere at any given time, whereas climate is what the statistics tell us should occur at any given time of the year (Burroughs 2007). Climate varies with geographical locations of the earth in relation to the latitude and altitude and with position relative to the mountains, oceans, deserts, etc. The climate of Antarctica is quite different from the climate of a tropical island.

15.2 Climate Has Significant Effect on Crop and Soil Management

Cultivation and management of crops require proper weather and climatic conditions. For example, we do not spray fertilizers and pesticides on wet rainy days. We do not till soil when it rains unless we prepare seedbed for a wetland crop such as rice. Climate has a deciding role in agricultural systems. Climate determines distribution of crops in different geographical regions, selection of cropping patterns and sequence, crop seasons, and management inputs. Seed germination, growth, flowering, fruiting, and ripening all are linked with climatic conditions such as temperature, moisture, and day length. Desired amount of rain does not fall in some years, or rain does not come when it is needed most. Crops may fail due to droughts in those years. Prolonged drought has been the cause of famine in some African countries. In some regions, cropping is rainfed; in many areas, ample irrigation water is not available during the growing season. Some weather conditions are favorable for specific kind of crop diseases.

Crop production is extremely susceptible to climate change. There will be major shifts in crop distribution due to climate change in the future. It has been estimated that climate changes are likely to reduce yields and/or damage crops in the twenty-first century (IPCC 2007a), although, notably, effects are expected to differ widely in different parts of the world. The warming of North America is already noticeable in the increased growing seasons and the northward movement of the limits of corn (maize) and soybean seed production growth. The Corn Belt will thus move into

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Table 15.1 Atmospheric concentration of major greenhouse gases

Greenhouse gas	Concentration[a] in 2007	Percentage increase since 1750
Carbon dioxide CO_2	383 ppmv	37
Methane CH_4	1,790 ppbv	156
Nitrous oxide N_2O	321 ppbv	19

WMO (2008), with permission
[a]*ppmv* parts per million by volume, *ppbv* parts per billion by volume

the Canadian Prairies. It was, however, observed in a study that the overall US crop production increased due to the beneficial effects of elevated CO_2 on crop yields and to marked precipitation increases. These two factors counterbalanced negative effects of warmer temperatures on crop yields. Rainfed crop production increased about 20–50%, especially benefiting winter wheat, corn (maize), soybean, and citrus crops.

15.3 Climate Is Changing

Climate has been changing due to natural and human-induced causes. Natural changes are slow and gradual, and ecosystems respond to these changes by changing themselves gradually and continually. Ecosystems tend to remain in equilibrium with their environment. This is known as ecosystem adaptation which is due to ecosystem resilience.

Human actions, including land use changes and agricultural activities, and burning fossil fuel have aggravated the climate change scenario further. Human-induced changes are rapid and abrupt, and ecosystems often fail to adjust to such changes. It has been much debated in the recent past whether climate is changing by human action and what should be the extent and consequences of such changes. Now, scientific community is virtually unanimous on this conclusion that human activities such as deforestation, biomass burning, soil tillage, drainage of wetlands, livestock farming and cropping, land clearing, and burning fossil fuel during the past 50 years have significantly increased greenhouse gases, such as carbon dioxide and methane, in the atmosphere (IPCC 2007b; CEICC 2008). Emissions of CO_2 in 2006 were about 36 billion Mg, almost 5.5 Mg for every human being (Raupach et al. 2007).

Table 15.1 presents the concentration of major greenhouse gases in the atmosphere. Carbon dioxide has increased by 37% in the atmosphere since 1750. Concentrations of other greenhouse gases have also increased. Methane and nitrous oxide have increased by 156 and 19%, respectively. Each molecule of methane and nitrous oxide absorbs 25 and 300 times more heat, respectively, than that of CO_2 (Prinn et al. 2000; Fluckiger et al. 2002). Greenhouse gas emissions have caused a rise in the temperature of the atmosphere. Projected changes indicate that some areas will get wetter and some drier and temperature will rise but at different rates in different regions. The change in climate would be exhibited by global warming, melting of arctic ice, sea level rise, and frequent occurrence of extreme events such as floods and droughts.

15.3.1 Climate Change Would Lead to Global Warming

IPCC (2007b) reported that the earth's average temperature is certainly warming. Global average surface temperature has risen some 0.75 °C since 1850. However, all parts of the planet's surface have not warmed at the same rate. Some parts are warming more rapidly than others while some other parts have slightly cooled. Projections for the twenty-first century in global temperature range from 1.8 to 4 °C. Warmer ocean waters cause sea ice to melt, result in many species shifting their geographic ranges, stress many other species that cannot move elsewhere, contribute to sea level rise, and hold less oxygen and carbon dioxide (CEICC 2008).

15.3.2 Arctic Sea Ice Would Melt Away

Sea ice in the Arctic Ocean expands in the winter and contracts in the summer. In the first half of the twentieth century, the annual minimum sea-ice area in the Arctic was usually in the range of 10–11 million km^2 (ACIA 2005). In September 2007, sea-ice area hit a single-day minimum of 4.1 million km^2, a loss of about half since the 1950s (Serreze et al. 2007). There is a decrease in thickness of the ice too. From 1975 to 2000, the average thickness of Arctic sea ice decreased by 33%, from 3.7 to 2.5 m (Rothrock et al. 2008).

15.3.3 Rising Sea Level Would Affect Coastal Environments

Sea levels are rising. Melted waters from glaciers and land ice add more volume to oceans. Warming also causes seawater to expand in volume. The global average sea level rose by 1.7 mm $year^{-1}$ in the twentieth century. Satellites measure the rate to be 3.1 mm $year^{-1}$ after 1992 (IPCC 2007a). Land is also subsiding in some coastal regions. Shoreline retreat has also been taking place as a result of sea level rise. Rising sea level inundates more coastal lands, causing changes in concerned ecosystems. Zervas (2001) indicated the rate of sea level rise at Baltimore, Maryland to be 3.12 mm $year^{-1}$ which is nearly double the present rate (1.7 mm $year^{-1}$) of global sea level rise. The higher rate might be due to land subsidence. Bangladesh, a southeast Asian country, will lose the largest amount of cultivable land due to sea level rise. A 1-m

Fig. 15.1 Flood in Bangladesh: climate change will dislodge people (Photo courtesy of the Daily Star)

rise in sea level would inundate 20% of the country's land mass (Rashid and Islam 2007).

Sea level has a profound influence on coastal environments, including beaches, barrier islands, wetlands, and estuarine systems. If the rate of sea level rise accelerates significantly, these systems will be affected adversely. If the sea level rises more rapidly than the capacity of ecosystems to accommodate, it could fundamentally change the state of the coast. Presently rising sea levels are submerging low-lying lands, eroding beaches, converting wetlands to open water, exacerbating coastal flooding, and increasing the salinity of estuaries and freshwater aquifers. Coastal installations including buildings, roads, and other infrastructures which are immobile are also vulnerable (CCSP 2009). Globally, 44% of the world's population lives within 150 km of the ocean, and more than 600 million people live in low elevation coastal zone areas that are less than 10 m above sea level (McGranahan et al. 2007), putting them at significant risk to the effects of sea level rise.

15.3.4 Hurricanes, Floods, and Droughts Would Be More Frequent

Extreme weather events including the most intense hurricanes have become more frequent (IPCC 2007b). Average annual precipitation patterns have changed in many places. At warmer temperature, moisture evaporates more quickly from land, so the amount of moisture available to plants may decline. More evaporation in oceans may lead to more cloud formation and more precipitation in some regions. However, patterns of changes in hydrology may be complex and uncertain. Many low-lying areas are flood-prone. Floods have already become frequent in many countries like Bangladesh (Fig. 15.1).

Floods and droughts are the products of patterns of wind, temperature, and precipitation that produce meteorological extremes. Floods and droughts are not isolated but are often related events driven by the same forces that shape the entire atmosphere. Drought is a sustained and regionally extensive occurrence of below average natural water availability. It is mainly caused by low precipitation and high evaporation rates. Drought is a recurring and worldwide phenomenon having spatial and temporal characteristics that vary significantly from one region to another. Drought and aridity are different environmental conditions; aridity is a long-term average feature of a dry climate. Water scarcity reflects conditions of long-term imbalances between available water resources and demands (Tallaksen and van Lanen 2004). However, the most severe consequences of drought are often found in arid or semiarid regions, where water availability is already low under normal conditions and demand is close to or exceeds natural availability. Climate change is expected to primarily affect precipitation, temperature, and potential evapotranspiration and, thus, is likely to impact the frequency and severity of meteorological droughts.

15.4 Properties and Functions of Soil Would Change in Response to Climate Change

Soils and climate are intimately linked systems. As climate is a driving variable of soil formation, it determines to a large extent the ecological functions a soil can perform. Again, soils have the potential to influence climate through greenhouse gas exchange with the atmosphere and by storing carbon. On the other hand, climate change can have a fundamental effect on functions and processes of soil. In the interplay of the soil and the atmosphere, the soil can be both a contributor to and a recipient of the impacts of climate change (Rosenzweig and Hillel 2000). According to Kardol et al. (2010), feedbacks of terrestrial ecosystems to atmospheric and climate change depend on soil ecosystem dynamics. A combination of rising atmospheric CO_2 levels and consequent changes in temperature, precipitation, windiness, and solar radiation will lead to changes in soil functioning. A rise in air temperature due to global warming would lead to concomitant rise in soil temperature in tropical, temperate, and arctic regions. Minor increases in soil temperatures in the tropics and subtropics and moderate increases with extended periods in temperate and cold climates were suggested by Emanuel et al. (1985). Increased soil temperature may enhance organic matter decomposition, soil structure deterioration, compaction and reduction in porosity, infiltration, and drainage (Lal 2004). These changes with alteration in microbial community and function may lead to soil fertility depletion. On the other hand, increased CO_2, precipitation, humidity, and biomass production may counteract some negative effects of temperature rise. A gradual improvement in soil fertility and physical conditions of soils in humid and subhumid climates has been suggested by Sombroek (1990).

15.4.1 Increased CO_2 May Enhance Biomass Production

Plant growth and carbon storage are likely to be enhanced by a "fertilization" effect of increased atmospheric CO_2. Since CO_2 is an essential ingredient of photosynthesis, as is water, photosynthesis would be faster and more efficient in enhanced atmospheric CO_2. A CO_2-enriched environment supports more growth and biomass production than would otherwise occur (Norby et al. 2005). But with limited water supplies, warming temperatures, deficiencies in other nutrients, or the influence of factors such as ozone that inhibit plant growth, the responses to increased levels of CO_2 are more complex and uncertain (Asshoff et al. 2006). Increased biomass production may lead to enhanced organic matter accumulation in soil and higher carbon sequestration.

15.4.2 Climate Change May Lead to Enhanced Decomposition of Soil Organic Matter

Primary producers (plants and other autotrophs) obtain CO_2 from the atmosphere and fix and convert carbon to biomass by photosynthesis. Decaying biomass subsequently and slowly accumulates in soils as organic matter. Meanwhile, in soil, root respiration and decomposition of organic matter return some carbon to the atmosphere as CO_2 (or as CH_4 under anaerobic conditions) and retain a part of organic matter in soil. Soil organic matter content is a fundamental property of soil because it determines the soil's capacity to facilitate many of its other functions, including retaining and transforming water, nutrients, and contaminants as well as sustaining biodiversity and storing carbon.

Organic matter is continually being added to soils and decomposed. The balance is retained in soil as soil organic matter. The carbon in soil organic matter is a significant component of the earth's carbon reservoirs, with around 1.5×10^{18} g C (Solomon et al. 1985). Significantly, more carbon is stored in the world's soils—including peatlands, wetlands, and permafrost—than is present in the atmosphere. If decomposition of soil organic matter is higher than addition, it becomes a source of atmospheric carbon dioxide. When decomposition is less than addition, soil becomes a sink of carbon dioxide.

As a result of elevated temperature, soil organic matter becomes vulnerable. The rate of biological and chemical transformations, including organic matter decomposition, increases with increasing temperature. The activity of decomposing microorganisms would also increase at elevated temperature leading to depletion of soil organic matter. An increase in temperature would deplete the soil organic carbon pool in the upper layers by 28% in the humid zone, 20% in the subhumid zone, and 15% in the arid zone (Lal 2004). However, if higher CO_2 concentration in air triggers net primary productivity and if increases of plant-derived carbon inputs to soils exceed increases in decomposition, the feedback would be negative (i.e., more carbon will be sequestered in soil). The present CO_2 concentration in the atmosphere, of 350 ppm, is suboptimal for plant growth in certain circumstances. The benefit to plants with the C_4 photosynthetic system is very small or zero because of their lack of photorespiration. In C_3 plants, there is undoubtedly the potential for increased growth of perhaps 30% if the CO_2 concentration rises to 600 ppm (Scharpenseel et al. 1990).

Despite much research, a consensus has not yet been reached on the temperature sensitivity of soil carbon decomposition. Reaching to a conclusion is difficult because the diverse soil organic compounds exhibit a wide range of kinetic properties relating to temperature sensitivity of their decomposition. Moreover, several environmental constraints obscure the intrinsic temperature sensitivity of substrate decomposition, and these constraints may, themselves, be sensitive to climate (Davidson and Janssens 2006).

15.4.3 Climate Change Would Increase Evapotranspiration

Evaporation is an important process of the hydrological cycle which involves the change of state of water from liquid to gas. Heat energy is absorbed during evaporation. So, evaporation from open water and soil is likely to increase as the temperature of the atmosphere rises. Through evaporation, water vapor enters the atmosphere, forms cloud, and falls as rain. Evaporation has a cooling effect on the earth because heat is being used for the process. But water vapor in the atmosphere acts as a greenhouse gas by trapping radiation.

The moisture holding capacity of the atmosphere increases with temperature. For every 1 °C increase in global temperatures, there is a 7% increase in the moisture holding capacity of the air. More moisture in the atmosphere ultimately leads to changes in rainfall patterns. Evaporation increases with the availability of water. More water is evaporated from a lake than from a dry soil. Moist areas like tropical rain forests have higher evaporation rates than arid regions. The amount of water that evaporates from the land surface depends on the amount that is contained in the soil.

Transpiration is the process by which terrestrial plants lose water to the atmosphere. More than 90% water that is absorbed by plants is transpired through the stomata in leaves. Leaves also intercept some rain which later evaporates to the atmosphere. As atmospheric temperature rises, so does evapotranspiration, leading to the loss of soil moisture. Plants may suffer from water stress in a warmer climate.

15.4.4 Climate Change Would Make Many Soils Saline

Soils become saline due to accumulation of soluble salts. Saline soils are problem soils, and many saline soils are not cultivable at all. Crop yield is significantly reduced, and crop failures may occur due to soil salinity.

Climate change is likely to increase all sorts of soil salinity: flooding of land by sea water in coastal areas, residual salt accumulation in arid lands, and capillary rise of salts from groundwater in humid areas. For rising sea level, flood water would make many low-lying areas saline. Sea water would intrude into inland fresh water through the river systems, and farmers would be compelled to use saline water for irrigation. The process is already advanced in many coastal riparian countries like Bangladesh. In this country, the flow of the main river system, the Ganges, has been interrupted by the Farakka Barrage in the upland watershed of Indian territory. The mighty river has dried in places, soils around have become droughty, and salt water has advanced inland through the estuary. This is an example how ill-judged human development activities cause environmental problems and lead to climate change.

Salinity in arid land soils is determined by precipitation and temperature variations. As temperature increases, evaporation and capillary rise of water also increase, resulting in soluble salt accumulation in the surface soil. Extensive observations on bore water levels and rainfall and general observations on the extent of dryland salinity have led to the conclusion that the extent of dryland salinity is related to the change in climate (Rancic et al. 2009). While a change in rainfall can alter soil salinity, the outcome depends on the condition of the soil as well as its position in the landscape (ERIC 2009).

15.4.5 Climate Change Would Alter Composition and Functions of Soil Microorganisms

Higher levels of atmospheric CO_2, warming, and changes in precipitation regimes simultaneously can have direct or indirect, positive or negative impacts on soil microbial communities. Precipitation and soil moisture changes may alter the ratio of bacteria and fungi, as well as shift their community composition (Chen et al. 2007). Rising temperatures can increase microbial activity, processes, and turnover, causing the microbial community to shift in favor of representatives adapted to higher temperatures and faster growth rates (Bradford et al. 2008). Elevated atmospheric CO_2 and precipitation changes might increase soil moisture in an ecosystem, but this increase may be counteracted by warming. Similarly, warming may increase microbial activity in an ecosystem, but this increase may be undone if changes in precipitation lead to a drier soil condition or reduced litter quantity, quality, and turnover.

Castro et al. (2010) suggested that the responses of the microbial communities to climate change that regulate ecosystem processes are less predictable. In a multifactor climate change experiment that exposed a constructed old-field ecosystem to different atmospheric CO_2 concentration (ambient, +300 ppm), temperature (ambient, +3 °C), and precipitation (wet and dry) to alter soil bacterial and fungal abundance and community structure, they found that (1) fungal abundance increased in warmed treatments; (2) bacterial abundance increased in warmed plots with elevated atmospheric CO_2 but decreased in warmed plots under ambient atmospheric CO_2; (3) the phylogenetic distribution of bacterial and fungal clones and their relative abundance varied among treatments, as indicated by changes in 16S rRNA and 28S rRNA genes; (4) changes in precipitation altered the relative abundance of *Proteobacteria* and *Acidobacteria*, where *Acidobacteria* decreased with a concomitant increase in the *Proteobacteria* in wet relative to dry treatments; and (5) changes in precipitation altered fungal community composition. They concluded that the direct and interactive impacts of climate change is likely to reshape bacterial and fungal soil communities and that changes in precipitation in particular will be important in dictating the response of microbial community composition in the future.

15.4.6 Temperature Rise May Lead to Permafrost Thawing

Permafrost is a layer of soil, in the cold zone, which remains permanently frozen. Permafrost is found in about 25% of the terrestrial ecosystems on the northern hemisphere (Zhang et al. 1999). It is found at a depth below the ground surface in some places in the boreal forest regions and in the surface

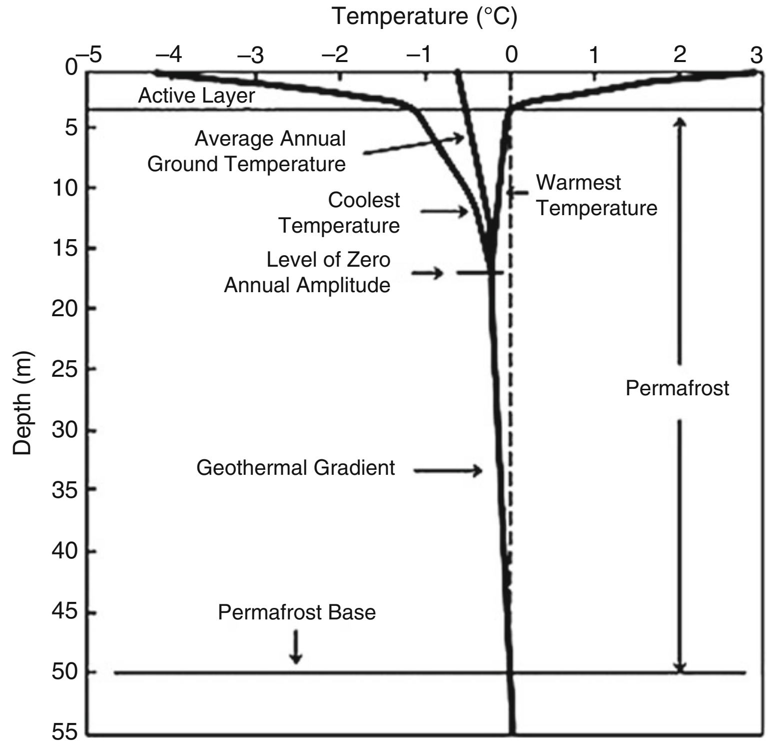

Fig. 15.2 Variation in temperature with depth in the permafrost region

of many other places in the arctic region. Where the permafrost occurs below the ground, the surface soil is frozen in the cool season and thaws in the warm season. This layer which undergoes alternate freezing and thawing is called the active layer. Thus, ground temperature of the active layer fluctuates with seasons, but the temporal variation in temperature decreases with depth. The point at which there is no discernable change in temperature is termed the "depth of zero annual amplitude" (Fig. 15.2). This depth varies from place to place.

Permafrost is a thermal condition. Environmental and anthropogenic changes that cause an alteration to the ground thermal regime determine its distribution, temperature, and thickness. However, the interaction between climate in the ground and below ground is complex and dependent on several factors influenced by climate change. Changes in climate above the ground are most often dampened below the ground due to the insulating effects of vegetation, organic material, or snow cover. There is generally a lag between a change in temperature at the ground surface and the change in permafrost at depth; for thick permafrost, this lag may be on the order of hundreds to thousands of years, for thin permafrost, years to decades.

However, in many parts of central and southern Mackenzie valley, Canada, permafrost temperatures are warm, 0 to −2 °C. Thus, small changes in ground temperatures associated with increased air temperatures will likely reduce the extent of permafrost, increase the depth of the active layer, and cause ground ice to melt (Couture et al. 2000). Numerous studies have reported permafrost degradation under climate warming in the twentieth century in the Northern Hemisphere (Camill 2005). Permafrost degradation may affect local hydrology, ecology, infrastructure, and even the climate (Zimov et al. 2006). In the period between 1989 and 1998, temperatures of upper permafrost layers have increased by 0.5–1.5 °C along a several hundred kilometer north–south transect in central Alaska and by 0.5–1 °C in the western Yamal Peninsula (Pavlov 1998). Reduction of extent of permafrost during the twentieth century has been documented for central and western Canada and Alaska (Weller and Lange 1999).

Climate models predict a mean annual temperature rise of 5 °C in the Arctic by the end of this century. A rise in temperature may have important consequences for the stability of permafrost soils. When permafrost thaws, it can cause the soil to sink or settle, damaging structures built upon or within that soil. The thickness of the active layer should increase at a warmer climate (Waelbroeck et al. 1997). Permafrost soils store twice as much carbon as is currently present in the atmosphere. If the permafrost thaws due to increased temperature, much of the carbon stored will be released to the atmosphere due to enhanced decomposition.

Thawing permafrost and the resulting mineralization of previously frozen organic carbon is considered an important future feedback from terrestrial ecosystems to the atmosphere. Hollesen et al. (2011) examined the Coup model to link surface and subsurface temperatures from a moist permafrost soil in high-arctic Greenland with observed heat production and CO_2 release rates from decomposition of previously frozen organic matter. Observations showed that the maximum thickness of the active layer at the end of the summer has increased 1 cm year^{-1} since 1996.

It was found in a study that artificially elevating summer temperatures by about 2 °C on plots of arctic tundra increased the CO_2 emissions by 26–38% under normal snowfall. When snowfall on some plots was increased which is one possibility with global warming, CO_2 emissions increased 112–326%. Thus, thawing permafrost might impact further climate change and soil carbon release. However, Blok et al. (2010) suggest that permafrost temperature records do not show a general warming trend during the last decade, despite large increases in surface air temperature.

15.5 Global Circulation Models Predict Future Climate and Its Impact

A global circulation model or a general circulation model (GCM) is a computer-based model that predicts future climate patterns in a place. It simultaneously applies several mathematical equations concerning the conservation of mass, energy, and momentum. From the outputs of model calculations, predictions of a number of climate patterns including ocean and wind currents to patterns in precipitation and evaporation rates that could affect lake levels and agricultural levels can be possible.

At present, the models show wind speed, wind direction, moisture, temperature, pressure, surface hydrologic processes, and radiation. New models for cloud prediction, more detail of ground physics, vegetation, the carbon cycle, and gas emissions are being developed. The Geophysical Fluid Dynamics Laboratory (GFDL) is engaged in developing and using mathematical models and computer simulations to improve our understanding and prediction of the behavior of the atmosphere, oceans, and climate. GFDL has prepared maps of the projected increase of surface air temperature. The warming is projected to be particularly large over much of the mid-latitude continental regions, including North America and Asia. Along with this surface warming, sea ice coverage over the Arctic Ocean is projected to decrease substantially. The sea level is expected to rise due to the thermal expansion of sea water as the ocean warms. Because the deep ocean will warm much more slowly than the upper ocean, the thermally driven rise in sea level is expected to continue for centuries after atmospheric CO_2 stops increasing. The sea level rise projections are the expected changes due to thermal expansion of sea water alone and do not include the effect of melted continental ice sheets. With the effect of ice sheets included, the total rise could be larger by a substantial factor. The sea level rise is not anticipated to be uniform over all regions of the globe due to the influence of ocean circulation changes as well as land movements unrelated to global warming.

Soil moisture as simulated in climate models refers to the amount of moisture available over land areas for humidification of the atmosphere. A highly simplified parameterization of soil moisture is used in the present GFDL climate model. The model simulates many of the observed large-scale climate features related to soil moisture content, such as major desert regions and moist temperate zones. Some persistent regional problems remain with these present-day simulations, including an excessively dry southeastern United States. In response to increasing CO_2, the GFDL model projects substantial decreases in soil moisture over most mid-latitude continental areas during summer (file:///C:/Documents%20and%20Settings/personal/Desktop/climate-impact-of-quadrupling-co2.htm).

15.6 Soil Management Should Also Aim at Mitigating Climate Change and Adapting to It

Soil management involves soil water, air, and nutrient management, soil organic matter and soil structure management, and management of soil microbial dynamics and nutrient cycling. Soil management aims at restoring soil fertility and productivity, conserving soil, and maximizing yield. The conventional soil and crop management practices include tilling, harrowing, weeding, fertilizing, irrigation, drainage, and liming. Such management has resulted in marked losses in soil organic carbon (including humus) and greatly reduced diversity and abundance of microbes (algae, bacteria, fungi, nematodes, protozoa) and larger organisms (e.g., mites, ants, beetles, worms) in the soil food web (Ingham 2006). Some cultivated soils have lost one-half to two-thirds of the original soil organic carbon with a cumulative loss of 30–40 Mg C ha^{-1}. The depletion of soil C is accentuated by soil degradation and exacerbated by land misuse and soil mismanagement. A considerable part of the depleted soil organic carbon pool can be restored through conversion of marginal lands into restorative land uses, adoption of conservation tillage with cover crops and crop residue mulch, nutrient cycling including the use of compost and manure, and other systems of sustainable management of soil and water resources. Measured rates of soil C sequestration through adoption of proper management practices range from 50 to 1,000 kg ha^{-1} year^{-1} (Lal 2004). Management of soil carbon is required also for soil health. Powlson et al. (2011) suggested that managing soil organic carbon is central because soil organic matter influences numerous soil properties relevant to ecosystem functioning and crop growth. Even small changes in total organic carbon content can have disproportionately large impacts on key soil physical properties.

Gain of carbon by soil ecosystems is mainly through input of biomass in the form of crop residues, compost, manure, mulch, cover crops, and alluvial or aeolian deposition. Soil and crop management practices that increase the soil carbon pool include slow-release formulations of fertilizer and use of zeolites (Oren and Kaya 2006), biofertilization via rhizobia–legume symbioses (Lugtenberg et al. 2002), increasing nitrogen fixation in legumes (Jones et al. 2007) and even in nonleguminous plants (Cheng et al. 2005), and improving soil structure.

Soil management practices at present should aim at mitigating climate change and adapting to climate change along with maintaining sustainable yield and restoring soil health. Mitigating climate change includes reducing emissions, sequestering emissions, and minimizing emissions. Adopting conservation tillage (no-till, minimum till), cover cropping, mulching, use of organic residues and composts, and biofertilization may benefit both mitigation and adaptation. Strategies to mitigate climate change also include soil restoration and woodland regeneration, nutrient management, improved grazing, water conservation and harvesting, efficient irrigation, agroforestry practices, and growing energy crops on spare lands. Numerous studies of replicated, long-term field experiments comparing conventional tillage (e.g., moldboard plow, chisel, disk) and no-tillage have demonstrated that most soils, following conversion to no-tillage, show an increase in soil organic carbon content relative to tilled soils (Ogle et al. 2005). In general, positive soil carbon responses are obtained first after several years of no-till management (Six et al. 2000), and after 20–30 years, the relative rates of C accumulation tend to decline as soil C levels approach a new equilibrium level under no-till conditions (West and Post 2002). FAO-CTIC (2008) lists the benefits of conservation tillage as (1) financial benefits to farmers; (2) greater stability in yields over varying climate years and with unfavorable weather; (3) higher ratios of outputs to inputs; (4) greater resilience to drought through better water capture and soil moisture retention; (5) reduced demands for labor and much lower costs of farm power (fossil fuels) and greenhouse gas emissions, through reduced tillage and weeding; (6) release of labor at key times, permitting diversification into new on- and off-farm enterprises; (7) better cycling of nutrients and lower losses of plant nutrients through accelerated erosion caused by inversion tillage; (8) higher profit margin because of increase in use efficiency of inputs; (9) increased land value over time because of progressive improvements in soil, water, and air quality; (10) decreased compaction; and (11) opportunities for crop diversification. The environmental benefits include (1) favorable hydrologic balance and perennial flows in rivers to withstand extreme weather events; (2) reduced intensity of desertification; (3) increased biodiversity both in the soil and the aboveground agricultural environment for nutrient cycling; (4) lower levels of soil erosion and sediments in rivers, dams, and irrigation systems; (5) greater carbon sequestration and retention in soils resulting in reduced emissions of greenhouse gases; and (6) less water pollution from pesticides and applied fertilizer nutrients.

Study Questions

1. What do you mean by weather and climate? How do you understand that the climate is changing? Why does climate change?
2. Discuss the impacts of global warming on soils sea level rise. Would there be any effect of temperature rise on emission of green house gases from soil? Why will climate change bring about a shift in the cropping patterns?
3. What is a permafrost? How would it react to climate change? What is the harm of permafrost thawing when most permafrosts are far in the arctic?
4. Discuss the impacts of climate change on vegetation and soil microorganisms. How will climate change affect biomass formation and decomposition?
5. How do GCMs predict climate change and its impacts? Discuss how soil management may help mitigation of climate change and adapting to it.

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