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IMPACTS OF CLIMATE CHANGE ON SOIL PROPERTIES

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ABSTRACT

Climate change has emerged as one of the most important environmental issues to confront agriculture production and food security. The causes of climate change are both natural and anthropogenic. The effects of climate change on soils are expected mainly through alteration in soil moisture conditions and increase in soil temperature and atmospheric CO_2 levels. Climate is one of the active factors of soil formation as temperature and precipitation has direct bearing on weathering of parent materials and soil profile development. A warmer climate accelerates chemical weathering of minerals and reduction in soil organic matter (SOM) due to increased microbial activity. Reductions in SOM can reduce the water and nutrient holding capacities, decrease the soil buffering capacity, and degrade the soil aggregate stability making it prone to soil erosion. The effects of climate change on soil chemical properties are mainly due to alterations in soil moisture. Soil moisture influences solute concentrations and thereby proportion of cations between soil solution and surface of soil organic and mineral colloids. Soil moisture also influences the oxidation and redox status of soil and thereby biological and abiotc transformations of plant nutrients in soil. The elevated atmospheric CO_2 induced climatic changes may affect the soil fertility and stoichiometry of trace metals. The increase in atmospheric CO_2 concentrations is also likely to intensify soil acidity due to enhanced soil respiration. Soil biological activities usually double with every 10 ^oC increase in temperature and thus increased temperatures accelerate rates of soil respiration. However, this increase in respiration will not continue to rise in temperature. Thus variables of climate change have differential influence on SOM oxidation and their interactive effect governs the quantity, quality and stability of SOM in soil. Soil microorganisms are often carbon limited and therefore, increased carbon availability though enhanced CO_2 levels stimulates microbial growth and activity. However, the response of soil microorganisms to changes under elevated CO_2 is highly variable and soil microbial biomass, gross N mineralization, microbial immobilization, and net N mineralization under elevated CO_2 show high variability. Climatic factors also have strong influence on thebiological nitrogen fixation.

INTRODUCTION

Soil seems to be more important for modern human societies than ever before to meet the global demands for food and fiber for increasing population from limited soil resources. The Fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) indicated that climate change is one of the major challenges influencing agriculture. Climate change is threatening food security globally. Countries like India are more vulnerable in view of the tropical monsoon climate and poor coping capacity of the small and marginal farmers. Climate change is projected to have significant impacts on agriculture through direct and indirect effects on crops, soils, livestock and pests. Though, climate change is a slow process involving relatively small changes in temperature and precipitation over long period of time, nevertheless these slow changes in climate influence the various soil processes particularly those related to soil fertility. The effects of climate change on soils are expected mainly through alteration in soil moisture conditions and increase in soil temperature and CO_2 levels as a result of climate change.

Climate change is global phenomena and is occurring continuously since the earth came into existence. There are well marked cold and hot cycles in the history of earth's climate, however, these changes have been observed relatively rapid in the last 150-200 years around the world (Fauchereau *et el*., 2003), owing to which climate change has become a major scientific and political issue during the last decade**.** The major causes of climate change include both natural and anthropogenic. Increase in atmospheric temperature due to the transmission of the incoming short wave radiations from the sun and absorbance of the outgoing long wave radiations together with release of green house gases (GHGs) like carbon di-oxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluoro carbons (CFCs) through human activities are major sources and cause of concern for changes in climate. The fourth assessment report of Intergovernmental Panel on climate Change (IPCC) made it clear that the global average temperature has increased by 0.74^0C over the last 100 years and projected increase is about 1.8 to 4.0^oC by 2100. The drivers of climate change such as moisture, temperature and CO_2 are expected to have variable effects on various soil processes and

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properties having relevance in soil fertility and productivity. However, these effects of the climate change factors can not be viewed separately, being one factor influence the other and resultant effect would be complex. Further, all these effects will be highly region specific, depending on the magnitude of the climate change, soil properties and climatic conditions. India is bestowed with 9 of the 12 soil orders that exist in world and 15 agro-climatic zones, with diverse seasons, crops and farming systems. Since climate change is a reality, it will have direct and indirect impacts on soil development processes and properties related to crop production influencing the livelihoods of millions of peoples in the country. The impact of climate change factors, specifically temperature, CO_2 and rainfall on various soil properties is being discussed below to understand the relationship between climate change variables and various soil properties in order to evolve appropriate mitigation strategies (Table 1).

Table 1: Summary of expected effects of individual climate change variables on soil processes

Increasing temperature	Loss of soil organic matter Reduction in labile pool of SOM Reduction in moisture content Increase in mineralization rate Loss of soil structure Increase in soil respiration rate
Increasing CO_2 concentration	Increase in soil organic matter Increase in water use efficiency More availability of carbon to soil microorganisms Accelerated nutrient cycling.
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 development

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 CO_2 levels. Climate change will influence soil moisture levels by direct climatic effects (precipitation, temperature effects on evaporation), climate induced changes in vegetation, plant growth rates, rates of soil water extraction by plants and the effect of enhanced CO_2 levels on plant transpiration. Changes in soil water fluxes may also feed back to the climate itself and even may contribute to drought conditions by decreasing available moisture, altering circulation patterns and increasing air temperatures. 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 dictates 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. 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. Bourgeon (2001) studied the weathering patterns in the Western Ghat (Sahyadri) region of India and proposed hydrolysis as the major process of weathering in this region. He has proposed that monosiallitisation was the dominant process in the western part and bisiallitisation was the dominant process in the eastern part of Western Ghats. 1:1 and 2:1 clays were considered to have formed by monosiallitisation and bisiallitisation, respectively. Deepthy and Balakrishnan (2005) compared the nature of clay minerals formed due to weathering in tropical regions receiving high rainfall (west coast of India, about 3m rainfall) and low rainfall (inland rain-shadow zones, < 200 cm rainfall). It was noted that in the west coast, 1:1 clays (kaolinite) and Fe–Al oxides (gibbsite/ goethite) were dominant clay minerals in the weathering profiles while 2:1 clay minerals were absent or found only in traces. In contrast, weathering profiles in the rain shadow region had more complex clay mineralogy and were dominated by 2:1 clays and kaolinite. Fe–Al oxides were either less or absent in clay fraction. This suggested that extent of chemical weathering was more in the western part as evidenced by presence of clay minerals dominant in iron aluminium oxyhydroxides and kaolinite irrespective of the parent rock type. The eastern part showed less intense chemical weathering and resulted in more complex clay mineralogy. It was proposed that rainfall and availability of water apart from temperature were the most important factors that determine kinetics of chemical weathering and weathering reactions of minerals proceeds through different pathways in water rich and water poor environments.

Soil moisture also strongly influences many soil forming processes, such as organic matter turnover, structure formation, weathering, podzolisation, clay translocation and gleying. The effect of soil temperature on soil development is largely due to its influence on production of biomass, organic matter decomposition rate and soil structure development. An increase in soil temperatures accelerates soil forming processes, leading to more rapid decomposition of organic matter, increased microbiological activity, faster release of nutrients, increased rates of nitrification and generally increased chemical weathering of minerals. Rainfall has significance in leaching rates of silica, iron and aluminum oxides and salts and has great bearing on soil profile development. Both soil temperature and moisture govern rates of plant growth and decomposition of organic matter. Humid cold climatic conditions favors slow decomposition and therefore faster soil development.

Soil physical properties

A typical mineral soil consist of four major components i.e., mineral matter (45%), organic matter (5%), soil water (25%) and soil air (25%). The physical properties of a soil depend on the amount, size, shape and arrangement of soil mineral particles and soil organic matter (SOM) content. The various size fractions of mineral particles namely sand, silt and clay, SOM and concentrations of inorganic ions are important for exhibiting various soil physical properties. The mineral soil particles together with organic fraction of soil forms the soil structure, which in turn govern the other physical properties of soil like soil water, porosity, bulk density, tilth, consistency etc. The characteristics like supporting power and bearing capacity, moisture storage capacity and its availability to plants, drainage, ease to penetration, aeration, retention of plant nutrients and its availability to plants are all intimately connected with the physical properties of the soil. The three major drivers of climate change i.e. increased CO_2, elevated temperature and rainfall influence the soil physical properties. The main effects of climate change on soil physical properties are through changes in soil moisture regimes as a result of alteration in precipitation and evapotranspiration loss and water use efficiency of crop plants. Change in rainfall may affect surface moisture availability and soil processes related to moisture content such as soil structure and associated moisture retention, release and transmission characteristics. The type of soil structure that develops under a particular climatic regime is particularly important because it affects the processes of run off, infiltration, percolation and drainage processes.

There is a close relationship between air temperature and soil temperature and a general increase in air temperature will inevitably lead to an increase in soil temperature. A warmer soil temperature will accelerate chemical weathering of minerals and reduction in SOM due to increased microbial activity. Rising temperature will also increase potential evapotranspiration from crops/ vegetation and land surfaces leading to a higher water demands, however it depends upon other related conditions such as humidity, wind velocity, etc. This will inurn adversely influence soil structure and related soil physical properties such as aeration, water holding capacity etc. The effect of higher temperature on soil physical properties would also be due to loss in SOM due to accelerated decomposition rate. Such reductions in SOM can reduce the water and nutrient holding capacities, decrease the soil buffering capacity, degrade the soil aggregate stability making it more susceptible to erosion and many other associated changes. This ultimately lead to decline in soil health and crop productivity. On the other hand, soil temperature is also affected by the type of vegetation occurring at its surface, which may change itself as a result of climate change. An increase in atmospheric CO_2 concentration is likely to improve soil physical conditions through greater supply of organic matter by increasing photosynthetic rates and water use efficiencies of crops.

Soil chemical properties

Soil chemical properties play pivotal role in availability of plant nutrients. Plants accumulate nutrients from the soil solution pool, and nutrients must be in solution to be mobile in the soil. Adsorption and desorption of cations on soil complex reactions are important chemical properties affecting nutrient concentration in soil solution for utilization by plants. The soil chemical properties usually influenced least by small change in soil temperature. However, these are strongly influenced by soil moisture. Soil moisture influence solute concentrations and thereby proportion of cations between soil solution and surface of soil organic and mineral colloids. A drying soil condition influence the balance between cation of lower valence (Ca^{++}) and cation of higher valence (Al^{+++}) on exchange site favouring Al+++ on exchange site and in soil solution. The increased Al+++ concentration in soil solution may increase soil acidity having adverse effect on soil biota and increased leaching of nutrients (Bolt and Bruggenwert, 1976). Rates of adsorption/ desorption reactions will accelerate with increased temperature, and changes in soil moisture may further modify reactions by altering the ionic strength of the soil solution.

Increases in air temperature and changes in precipitation have significant impacts on soil temperature and moisture regimes. These factors of climate change have great bearing on the nutrient cycling in soil. Biological transformation between organic and inorganic pools is strongly influenced by moisture and temperature, and thus, global climate change may strongly influence solution concentrations of nitrogen, phosphorus and sulphur. Increased soil temperatures generally accelerate decomposition of organic matter due to increased microbiological activity leading to rapid release of nutrients. Pendall *et al.* (2004) suggested that increased CO_2 may not exert a significant direct effect on N mineralization, but associated warming can cause increased N mineralization, leading to increased solution-phase N. Besides, the other microbial mediated process related to nutrient availability such as biological nitrogen fixation, phosphorus solubilization, nitrification, denitrification, sulphur oxidation and reduction are highly dependent on soil temperature and soil moisture. The elevated atmospheric CO_2 induced climatic changes in soil properties may affect the biological storage and stoichiometry of trace metals. Natali *et el.* (2009) examined CO_2 effects on some metal micronutrients and contaminants in forest trees and soils and found that CO_2 effects on soil metals were variable across sites and are associated with CO_2 effects on SOM. Dijkstra *et al.* (2010) indicated a more closed N cycle under elevated CO_2 and a more open N cycle with warming, which could affect long-term N retention, plant productivity and C sequestration. They evaluated the combined effects of elevated CO_2 and warming on N cycling under ambient and elevated CO_2 concentrations (600 µmol mol-^{1}) and ambient and elevated temperature (1.5 : 3.0^{o}C warmer day:night) in semiarid grassland field. Soil inorganic N significantly decreased under elevated CO_2, probably because of increased microbial N immobilization, while soil inorganic N and plant N pool sizes significantly increased with warming, probably because of increased N supply. They observed no CO_2 x warming interaction effects on soil inorganic N, N pool sizes or NO_3 uptake in plants and microbes. These influences of climate change on nutrient availability will differ in different regions as the nature and extent of the change in soil moisture and temperature will be site and soils specific Soil moisture and temperature are also primary determinants of root growth and development affecting nutrient use efficiency through direct impacts on root surface area and metabolic function.

Oxidation and redox conditions of soils are important in biological and abiotc transformations of plant nutrients in soil. The biological mediated nutrient transformation processes that are influenced by soil redox conditions include oxidation and reduction of nitrogen, phosphorus and sulphur during mineralization, nitrification and denitrification. The abiotic oxidation – reduction reaction of soil are mainly oxidation and reduction of Fe and Mn and conversion of nitrate to nitrite to some extant. Soil moisture together with availability of decomposable organic matter is the main factors for controlling oxidation-reduction state of soil. An increase in temperature without any change in rainfall would cause a reduction in soil moisture to favour oxidation state. It would favour the biological activity leading to increased availability of nitrogen and sulphur. On the other hand, an increase in precipitation would favour reduced soil conditions causing loss of nitrogen through denitrification and sulphur avaiablity due to its reduction as suphide. The elevated CO_2 levels also have indirect impacts on soil redox conditions through altering plant growth and supply of decomposable organic residue.

Soil pH has variable effects on the solubility of ions in soil solution and influences the availability of plant nutrients to great extant. An increase in atmospheric CO_2 concentrations is likely to intensify soil acidity due to enhanced soil respiration under elevated CO_2 conditions. The formation of more carbonic acid (H_2CO_3) in soil water will accelerate leaching of base cations from the soil, thereby causing soil acidification. In fact, it is believed that increases in atmospheric CO_2 since the interglacial era have gradually acidified soils throughout the world (Oh and Richter, 2004) and will continue to do so in the high CO_2 atmosphere of the future. A long dry spell in water logged soils would lead to conversion of reduced sulphur compound to sulphate consequently causing reduction in soil pH (Warren *et al.* 2001). Salinization is a problem that has long being associated with agriculture and is the result of inappropriate practices. In addition, agriculture intensification, as well as changes in temperature and precipitation patterns expected from climate change, are likely to further affect the salt-water balance of soil ecosystems. It would be of more significance in areas were climate change scenarios predicts drought or rise in sea level. The high evaporation of water from soil under warmer climatic conditions would bring salts to surface soil layers leading to development of soil salinity.

Soil biological properties

Soil contains numerous and diverse living organisms ranging from the myriad of invisible microbes, bacteria and fungi to the more familiar macro-fauna such as earthworms and termites. These diverse microorganisms interact with one another, with the plants and soil inorganic constituents forming a complex system of biological activity. Soil microorganisms and fauna are main drivers of organic matter decomposition and hence have significant influence on nutrient cycling, organic matter turnover, degradation of xenobiotics and soil structure. The variable of climate change, particularly soil moisture, temperature and CO_2 influence the activity of these organisms to varying extant.

Soil organic matter is central to the different soil biological properties being major source of nutrition for soil microorganisms. The variables of climate change have differential influence on soil organic mater and their interactive effect governs the quantity, quality and stability of SOM in soil. Climate change variable have impact on SOM directly through temperature and precipitation by altering land use and rate of addition and decomposition of organic residues. Kirshbaum *et al.* (1996) reported that SOM contents generally increase with soil water content and decrease with temperature. Net primary productivity (NPP) usually increases with increasing temperature and elevated atmospheric CO_2, leading to greater returns of carbon to soils, but increasing temperature accelerates decomposition at rates exceeding to NPP leading to reduction in SOM contents. However, the rates of decomposition vary with composition of generated organic residues. At higher temperatures, there is enhanced decomposition of SOM, particularly the labile fractions that are more important for nutrient supply, with an increasing proportion of relatively inert carbon fractions. In contrast, excess soil water as a result of increased precipitation will reduce decomposition rates (Kirschbaum, 1995) and thus will have positive impacts on SOM contents.

The response of soil microorganisms to changes in plant production under elevated CO_2 is highly variable due to very different patterns of plant C allocation in different plant–soil systems. Microbial biomass, gross N mineralization, microbial immobilization, and net N mineralization under elevated CO_2 show a high degree of variability. However, rates of soil and microbial respiration are generally more rapid under elevated CO_2, indicating that enhanced plant growth under elevated CO_2 increases the amount of C entering the soil, thereby stimulating soil microbial activity. The increased CO_2 concentrations on one way limits the availability of plant nutrients because of their sequestration in plant biomass and SOM pools (Luo *et al.* 2004), but on the other hand will have potential negative effect on the carbon sequestration in soils due to alteration in release of root derived compounds. It has been reported that plants under elevated CO_2 decrease their allocation of N-rich metabolites and increase the allocation of C rich metabolites to root exudates (Tarnawski and Aragno 2006) and results in an increase in microbial activity and consequently the CO_2 production. Several studies using C isotope tracers have demonstrated that the production of CO_2 in the rhizosphere by roots and microorganisms is significantly stimulated by elevated CO_2 plant growth conditions. Such stimulation of CO_2 respiration in the rhizosphere may be much higher than the enhancement of root biomass. Cheng and Johnson (1998) demonstrated that although plants produced only 15–26% more biomass under elevated CO_2, rhizosphere respired C increased by 56–74% as compared to ambient CO_2 treatments. The change in SOM turnover rates is expected to cause a decline in soil organic nitrogen on long term basis, although, in the short term, increased returns of carbon to soils would maintain soil organic nitrogen contents. Greater mineralization due to increased microbial activities at elevated temperature may cause an increase in nitrogen losses from the soil through volatilization.

Biological nitrogen fixation (BNF) reportedly brings about 175×10^9 kg N annually to soil from atmosphere (Paul and Clark 1996). Climatic factors such as temperature and moisture have strong influence on the N_2-fixing activity of rhizobia and free living diazotrophs. Root temperature affects many events of legume-rhizobia symbiosis; however the effect of root temperature is complex and varies with host species as well as associated rhizobia. Events of symbiotic process have different optima and limiting temperatures. Normally for temperate legumes optimum temperature range for good nodulation and nitrogen fixation is 15-25°C and for tropical and subtropical legumes it ranges between 25 and 35°C. Nitrogenase activity of chickpea nodules was adversely affected at 30°C (Chandra 1985). High root temperature (32°C) inhibited the nodulation in chickpea (Dart *et al.* 1976). Although, minimum and maximum temperature ranges for nodulation of tropical and subtropical legumes are 15-18° C and 35-40° C, respectively, the symbiotic systems have tendency to compensate for adverse effects of moderately low or high temperatures by either forming more nodules or fixing more nitrogen per unit nodule weight (Gibson, 1976). An increase in atmospheric CO_2 concentration usually increases N_2-fixation in root-nodulated plants. However, neither the efficiency nor the cost of the N_2-fixation process seems to be directly related with elevated CO_2. The effects of increased CO_2 on N_2 fixation have been attributed mainly due to increases in root biomass and hence, number of nodules per plant and/or changes in the individual weight of the nodules (Soussana and Hartwig, 1996). Soil moisture also influences the mobility of rhizobia and function and N_2 fixing activities by microorganisms, however the moisture which is sufficient for seed germination is also enough for the various steps of BNF.

Soil microorganisms are often carbon limited and therefore, increased carbon availability stimulates microbial growth and activity. It is generally assumed that the CO_2 induced increases in soil C availability will increase fungal biomass more than bacterial biomass. It is because of increased concentrations of dissolved organic C in the rhizosphere and to increases in soil water dissolved organic N. Since fungi plays important roles in organic matter degradation, nutrient cycling, plant nutrition, and soil aggregate formation, a shifts in fungal communities might have a strong impact on soil functioning. Furthermore, lower N availability at elevated CO_2 may, in part, explain these increases in fungi, as fungi tend to have a higher C/N ratio than bacteria and so have a lower demand for N than bacteria (Hu *et al.* 2001). Bacteria and fungi serve as substrates for a multitude of tiny predators and grazers, including protozoa, nematodes, and arthropods in soil. Therefore, an increase in bacterial growth due to an increasing C allocation at elevated atmospheric CO_2 levels may be followed by an increase in population of grazers, resulting in a higher turnover of the microbial biomass.

In general, soil biological activities doubles with every 10 ^{o}C increase in temperature. Several studies showed that increased temperatures accelerate rates of soil respiration. However, this increase in respiration will not exist as temperatures continue to rise. In a 10-year soil warming experiment, Melillo *et al.* (2002) showed that a 28% increase in CO_2 flux in the first 6 years of warming when compared to the control soils, followed by considerable decreases in CO_2 released in subsequent years, and no significant response to warming in the final year of the experiment. The exact microbial processes that cause this decreased long-term response to warming conditions are not clearly known, but explanations such as that increased temperatures caused microbes to undergo physiological changes that result in reduced carbon-use efficiency (Allison *et al.*, 2010) or acclimatization of soil microbes to higher soil temperatures by adapting their metabolism and eventually return to normal decomposition rates have been proposed. A great variability has been reported in the response of soil community function to climate change and the potential effects of these responses at the ecosystem level (Smith *et al.*, 1998). Most soil biota has relatively large temperature optima and therefore are unlikely to be adversely affected by climate change (Tinker and Ineson, 1990), although some evidence exists to support changes in the balance between soil functional types (Swift *et al.*, 1998). Soil organisms will be affected by elevated atmospheric CO_2 concentrations where this changes carbon substrate and soil moisture regime (Rounsevell *et al.*, 1996). Furthermore, the distribution of individual species of soil biota will be affected by climate change where species are associated with specific vegetation and are unable to adapt at the rate of land-cover change (Kirschbaum *et al.*, 1996).

The effects of elevated atmospheric CO_2 concentration on soil microbial community structure are often characterized by an increased mycorrhizal colonization. CO_2 enrichment increases mycorrhizal biomass because plant demands for N and P increase simultaneously with increase in C assimilation rates, and plants allocate more photosynthates below ground to the roots and mycorrhizal fungi. Greater fine root mass and mycorrhizal infection promote enhanced P uptake in mycorrhizal plants grown under elevated CO_2 concentrations. It seems reasonable to expect that at elevated CO_2 levels, mycorrhizal biomass will increase as C becomes relatively less limiting and soil nutrients become more limiting to plant growth. However, Diaz (1996) showed that increased mycorrhizal activity at high CO_2 was mostly due to increased root biomass with the consequent increased mycorrhizal infection, rather than a change of the infection per unit root production (biomass or length).

Soil degradation

Soil degradation refers to the temporary or permanent lowering of the productive capacity of soil due to processes such as soil erosion, nutrient runoff, leaching losses, acidification, desertification, salinization, organic matter reduction and accumulation of toxic substances. Climate change has significant consequences on various soil degradation processes. Water erosion is one of the most serious degradation problems of the Indian soils covering an area of 148.9 M ha. Problems of soil erosion are related to reduction in SOM content and water holding capacity of soil making them more prone to loss through runoff. Rill erosion is directly related to the amount of precipitation; hence the severity, frequency and extent are likely to be influenced by change in amount and intensity of rainfall due to climate change. Another most serious soil degradation problem is of excessive wetness due to water logging. The estimates show that the soil area prone to water-logging in India is 11.6 M ha. Wind erosion is a serious problem in the arid and semi-arid regions of Rajasthan, Haryana, Gujarat, Punjab and coastal areas. Wind erosion may increase sharply due to reduction of organic matter as result of increased oxidation as of rise in temperature. Alteration in timing and distribution of rainfall pattern and its intensity due to climate change may significantly increase erosion in some regions, through heavy rainfall and increased wind speed.

Soil salinity and sodicity development are the emerging soil degradation problems due to changes in land use pattern and land cover, which are likely impacts of climate change variables. In coastal area, coastal aquifers are important source of fresh ground water. However, due to excessive use of fresh water for agriculture and horticultural purposes may result a fall in fresh water table below sea level allowing water from sea to replace fresh water volume in adjoining area. Due to rise in temperature, evaporative demand for water increases leading to development of salinity in these areas due to upward movement of salts. The increase in salinity in coastal regions may also occur due to rise in sea water level as a result of climate change. Climate change is expected to significantly alter ground water recharge rates of major aquifers in function of the reduction of ground water recharge rates resulting in a reduction of fresh ground water resources. In such conditions, the effect of rise in temperature in salt affected area will increase the severity of salinity. Desertification may results from various factors, but climatic variations might exacerbate desertification through alteration of spatial and temporal patterns in temperature, rainfall, solar radiation and winds. Several climate models have predicted that rise in temperature will reduce soil moisture and negatively affect vegetation growth. High temperature and low rainfall in the drylands lead to poor organic matter production and rapid oxidation. Low organic matter will lead to poor aggregation and low aggregate stability leading to a high probability for wind and water erosion. It may cause an increase in area under desert land.

Adaptation and mitigation strategies

Climate is the only factor associated with crop production on which man has no control. However, the adverse effects of climate change on soils can be reversed or minimized by adoption of appropriate soil management practices. Globally, an increase in soil carbon (Carbon sequestration) offers great mitigation potential. The amount of carbon sequestered at a site reflects the long-term balance between carbon addition and losses mechanisms. Many agronomic, forestry, and conservation agriculture practices leads to a beneficial net gain in carbon fixation in soil. Elevated CO_2 levels usually have positive impacts on carbon sequestration as plants photosynthesize atmospheric CO_2 into plant biomass. Subsequently, some of this plant biomass is indirectly sequestered as soil organic carbon (SOC) during decomposition processes. However, the net effect of this process on C storage in soil is controlled by rate of decomposiopn of SOC, which generally increases with increased soil temperature. The C sequestration potential of a soil further depends on climate, the type of vegetation it supports, the nature of parent material, the depth of solum, soil drainage, the edaphic environment, soil SOM content and its decomposability and land management practices. Management practices or technologies that increase carbon input to the soil and reduce C loss or both lead to net carbon sequestration in soils. Increased C input in agro-ecosystems can be achieved in a number of ways such as selection of high biomass producing crops, residue recycling or residue retention by lessened tillage intensity, application of organic materials (e.g. animal manure, compost, sludge, green manure etc.), adoption of agroforestry systems, intensification of agriculture through improved nutrient and water management practices, reducing summer or winter fallow, changing from monoculture to rotation cropping, and switching from annual crops to perennial vegetation. Soil carbon loss could be decreased by adopting conservation agriculture and minimizing soil disturbance, checking erosion through reduced tillage intensity, and using low quality organic inputs. Technological options that have been found to be efficient for soil C sequestration in Indian agro-ecosystems include integrated nutrient management and manuring, crop residue incorporation, mulch farming and/conservation agriculture, agro-forestry systems, grazing management, choice of cropping system and intensification of agriculture

Conclusions and future thrust

Climate change is inevitable phenomena and caused by anthropogenic activities due to increase in concentration of GHGs in the atmosphere. Climate change has direct effects on plant growth and productivity through alterations temperature, precipitation, atmospheric CO_2 concentrations etc. Besides, climatic climate change variables have great influence on soil physical, chemical and biological properties. An increase in atmospheric temperature, in addition to the direct effects on weathering of soil minerals and soil formation, determines soil C status by influencing oxidation. Soil C being central to many soil functions, in turn influences soil structure, soil fertility and soil biological functions. However, these effects of climate change on soil properties are complicated and depend on the relative effects of different variables of climate change in a given region and soil and crop management practices. Thus, efforts are necessary to develop soil management strategies to reverse the negative impacts of climate change on soil properties. It warrants focused research to understand the effects of climate change on soil properties in different agro-ecological conditions in order to ensure sustainable soil health. Implementation of climate change mitigation strategies requires decisions at different levels and mitigation practices that recover investment cost and generate a profit in the short term be preferred over practices that require a long term to recover their investment costs. Following are some of the suggested strategies to minimize the risks of climate change on soil health.

- Comprehensive research should be carried out for understanding the effect of climate change on soil processes and soil properties under different agro-ecological conditions.
- Quantification of the impacts of management practices on soil carbon dynamics for different agricultural production system.
- To evolve soil and crop management practices or technologies that increase carbon input to the soil and reduce C loss or both leading to net carbon sequestration in soils.
- Research on prediction of climate change impacts on soil quality should be carried out in long-term studies in FACE (free air CO2 enrichment) and FATE (free air temperature enrichment).
- Development of a GIS based soil monitoring systems for assessing the risk of climate change soil quality and Integration of geographic information and socioeconomic information for site specific mitigation technology.

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