Climate Change: Impacts on Carbon Sequestration, Biodiversity and Agriculture

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Abstract Climate change is a wider term and encompasses every aspect of biotic and abiotic life. Climate plays a very basic and significant role in the biology of living things. As a result the key factor amongst many to determine life in specific region thousands of years ago is the fact that various climate cycles existed at that place at that times. The recent decades have witnessed drastic changes in climate because of rise in atmospheric carbondioxide (CO_2) and ozone (O_3) levels leading to increase in temperature, melting of glaciers and rise in sea level. The ultimate trends that CO_2 and climate will constitute in the future are unknown. However, the researchers have been raising questions about carbon sequestration, food security, and crop productivity in the field of agriculture and extinction of species in the field of biodiversity. The term carbon sequestration implies the ways and means through which atmospheric carbon is transferred into the long lived pools and storing it safely in a way that it may not be re-emitted into the atmosphere. Anthropogenic activities, over a period of time have raised serious concerns to sequester carbon and lower down its concentration in the atmosphere, hence leading to drastic climate changes. Since it is not possible to cover all aspects of climate change, in this review we have emphasized on green house and non-green house aspects of climate change and their potential of global warming, implications on carbon sequestration sustainability and agriculture.

Keywords Climate change • Soil carbon sequestration • Sustainable agriculture • Global warming

1 Introduction

There are several signs of life on the earth even at the places life does not exist today. These signs are in the form of chalk or fossils. It is also important to note that the signs of life of different species found today are different from the species found today. This difference is due to evolution; however, the reason for the presence of one type of species at one place and absence at another place is the climate. Climate plays a very basic and significant role in the biology of living things. As a result the key factor amongst many to determine life in specific region thousands of years ago is the fact that various climate cycles existed at that place at that times (Cowie 2013; Hakeem 2015).

It is quite convenient to use this biological fact to study the climate. These biological remains are the imprints of past climate. Moreover, biology has a very significant influence on climate i.e. transpiration of rainforests can influence the flow of water in a catchment area, it means it can transform climate otherwise it would have been in the absence of living organisms. Looking from another angle, all living organisms have a certain optimum temperature range for their growth and development and flourish well in that range. Similarly, water requirement of all organisms are different for completing their life cycles and availability of water is controlled by the environment. Taking into account the connection of water and temperature with life, it is very easy to determine the habitats of different species and their ecosystems.

From this discussion if we can understand the significance of climate then it is imperative to understand the climate change for prediction of the fate of different species in different ecosystems. It is also possible to use reverse in an applied sense to record the past presence of various species and take it as an indicator of climate change. This is the very basic interrelationship between climate and life and affects all living things and we tend to shun the fact that every continent except Antarctica has signs of extinct civilizations and settlements which used to be the flourishing centers of the world which no more exist fundamentally because of the climate change.

If we assume that living things are not subject to climate change, there is sufficient evidence to prove the alteration of climate by global societies in a way which has deep global, biological, and regional implications that will impart profound impact on living things and create interactions between the two.

2 Difference Between Weather and Climate

To understand the biology of climate it is imperative to know about the climate and weather and differentiate between the two. We listen about climate and weather quite often however; there is a lot of confusion over the two terminologies. Every one of us checks the weather forecast for every planning and climate change is the news of the day. In simple words, climate is the forecast and weather is the outcome. Weather is what we see outside on any day of the year. For example it may be 40° C and sunny or 20° C and cloudy (National Oceanic and Atmospheric Administration 2015). Climate is the average of that weather. For example one can expect heavy rains in the Northeast in July or it to be hot and humid in Southeast in July. The outcome is that the climate change is a long term phenomenon and weather is a change for short period of time.

There are many factors of climate and weather at a place however; major elements are temperature, pressure, wind, humidity and precipitation. The study and analysis of these factors provides the basis of weather and climate forecasting. These factors make the basis of climatology.

3 The Greenhouse Effect

The better understanding of the greenhouse effect may be obtained by considering that the Earth has no atmosphere. To understand this process we have to consider the information on the Moon surface. As we know the Moon surface is airless, its day time temperature is 117 °C and it drops to −173 °C at night rendering a median of −28 °C. During the day time its surface either absorbs the Sun light and warms the rocks or reflects off. On the other hand the Earth's surface average temperature is 15 °C, which is due to the fact that the Earth's surface keeps it low, otherwise it would be 43 °C. This is due to the greenhouse effect of the Earth. This warming effect is natural and existed always. This warming occurs because all the radiations coming from the Sun are not reflected by the Earth's surface. Some of the radiations are trapped on the surface of the Earth just like on the surface of the Moon rocks trap them however, trapping of the radiations is more on the Earth's surface because its atmosphere is more transparent for the high wavelength radiations and opaque to the short wavelength radiations. Contrary to this rocks on the Moon surface are not transparent and only their surface warms, not strata in deep.

The reason of the reflection of some of the light back to the atmosphere is that for some of the light the atmosphere becomes transparent. These are mostly long wavelength radiations and are reflected back to the atmosphere while short wavelength radiations are trapped and cause the temperature to rise. Its function is similar to the glass of a greenhouse which allows the higher wavelength light in and traps some of the lower wavelength radiations; therefore this phenomenon is called greenhouse effect. That is the reason why the components of the atmosphere which show such properties are called greenhouse gases.

4 Greenhouse Gases

Many gases known as greenhouse gases occur naturally at various concentrations. These include water vapors (H_2O), methane (CH_4) nitrous oxide (N_2O) and CO_2. Other most important included in this category are chloloroflorocarbons (CFCs) which are artificial and are used as coolants or foam blowing. Carbon dioxide is the main gas whose concentration is increasing day by day due to human activities.

Tyndall (1861) recognized greenhouse gases and narrated their possible implications if their concentration changes in the atmosphere (Hulme 2009). He also speculated the possibilities of no warming effect if concentration of these gases decreased in the atmosphere. Consequently the Earth may face another ice age. However; this phenomenon is reverted due to increasing concentration of greenhouse gases which cause the warming effect. The main reason behind current global warming is the difference between natural greenhouse effect and the human generated effect (Cowie 2013). Today the atmosphere is changing with ever increasing concentrations

Table 1 Summary of major greenhouse gases (1765–2015)

Greenhouse gases	1765	1990	2005	2011	2015
$CO_{2\ (ppm)}$	280	354	380	392	400
$CH_{4\ (ppb)}$	730	1720	1770	1800	1840
CFC-11 $_{(ppt)}$	0.0	258.45	250.56	238.11	232.23
CFC-12 $_{(ppt)}$	0.0	485.20	542.80	529.57	519.73
$N_2O_{(ppt)}$	270.47	308.07	319.10	324.32	328.11

The values of CFC-11, CFC-12 and N_2O are average of concentrations at Northern and Southern hemispheres. Cowie (2013); Leung et al. 2014; Bullister 2015. *ppt* parts per trillian, *ppm* parts per million. http://cdiac.ornl.gov/ftp/oceans/CFC_ATM_Hist/CFC_ATM_Hist_2015/NDP_095(2015).pdf

of CO_2 due to burning of fossil fuels. The following table illustrates the periodic increase of CO_2 concentration in the atmosphere (Table 1).

Since the Industrial Revolution the Earth has encountered various cycles of warmth although the warmness is not directly proportional to the increase of greenhouse gases but the fact is that the warming of the Earth has taken place. Today we know that with less concentration of greenhouse gases in the atmosphere the Earth cools and there is ice age; when the Earth was cool and the atmosphere carbon dioxide concentration was less.

Methane and CO_2 are part of global carbon cycle and nitrous oxide forms part of nitrogen cycle and all the three gases have natural and human origin. Nitrous oxide is released by the decomposition of organic matter by tropical forests, soils and oceans. Organic matter burning and fertilizers are among the anthropogenic activities that contribute towards N_2O in the atmosphere. Removal of N_2O from atmosphere is carried out by a process known as photosynthesis in the presence of sunlight which results into the release of N_2 and $O_{2.}$

Another important greenhouse gas that has not captured a lot of attention so far is water vapor. It is a powerful greenhouse gas and is playing a significant role in global warming. Atmosphere has sufficient concentrations of water vapors which absorb the infra-red radiations from the Sun. These water vapors are present everywhere in the atmosphere, even over the Sahara Desert however; the concentration is not constant throughout the atmospheric column (National Oceanic and Atmospheric Administration 2015; Cowie 2013). These vapors absorb radiation and cause rise in temperature. In a warmer world there will be more evaporation from the surface of the Oceans, hence will contribute more water vapors that will double the warming.

5 Global Warming Potential of Greenhouse Gases

Each greenhouse gas has different physico-chemical properties and has different warming potential to the atmosphere. Their properties are quantified for global warming potential (GWP) which is defined as a “comparative index for unit mass of a gas measured against the warming potential of a unit mass of carbon dioxide over a specific period of time". Since all greenhouse gases have different atmospheric residence time so GWP must be expressed in certain time period otherwise this will make no sense. If we take the example of methane, whose atmospheric residence time is 12 years and a quarter after 2 years which means that average life time of a molecule of methane would be 12 year^2. On the other hand N_2O has an average residence time of over 100 years. If we compare the GWP of N_2O and CH_4 over a decade will give different warming value. It means GWP of the greenhouse gas will vary with the nature of the gas and the time of residence. Even the GWPs determined by IPCC vary in their different reports. There are several other agents that also contribute to the global warming, among these chloroflorocarbons (CFCs), hydrochloroflorocarbons (HCFCs) and hydrofluorocarbons (HFCs) are well known. Human made chemicals have low atmospheric concentrations and their contribution is less than a quarter of present warming (Cowie 2013).

6 Non-Greenhouse Influences of Climate

There are several non-greenhouse aspects which play role although not a major one in the climate changes. Milankovitch variation and changing sun light-reflecting properties of ice caps explain these processes. Although there is a clear understanding among the climate community that man-made addition of greenhouse gases are the main contributors towards the climate change yet non-greenhouse factors cannot be ignored altogether. One of these is solar output which has played a key role for billions of years on the Earth. The Sun being a main star in this sequence is getting warmer over a period of billions of years and has imparted considerable implications on the biosphere. However for a shorter time period of hundreds to thousands of years it is relatively stable. Even shorter time scale of the Sun has impact on the climate. This impact is not very significant and only causes a variation of 0.08 % in the irradiance which may have the potential to change global climate by 0.02–0.04 °C (Foukal et al. 2004).

Cowie (2013) has reported that the scientists have been taking space-born measurements of solar output and have been correlating it with sun sport activity since 1978. The process is not clear but the interaction exists. The solar component is another term which is five times in magnitude as compared to the solar variation reflected by sun sport activity. Moreover there exists a correlation between solar output and global temperature but it is not clear that this relationship is real or partial.

It can be concluded that there are several factors impacting the climate positively and/or negatively. Out of these factors some are strong and some are weak; for example greenhouse gases are strong factor and the variations in the sun's output over a thousand of years are weak factors. However their superimposition may help trigger larger changes in the concentrations of methane and CO_2 as the Earth moves between inter glacial and glacial modes. Therefore it must not be surprising to note that greenhouse gases are not the sole source of global warming. There are other non-greenhouse factors such as solar output, volcanic eruption, oceanic and atmospheric circulations and marine release of methane. Although these factors contribute towards the global warming yet they are not the main contributors. At the same time these cannot be neglected and they may be contributing to global warming in future especially the circulation changes.

7 Global Warming and Impacts on Future

The response of natural system and species to climate change is an intricate process, moreover certainly become a bit more complex. Some responses are quite opposite to the expectations. One thing is common and that is the fact that our planet is warming up. The data presented by different researchers (Cowie 2013; National Oceanic and Atmospheric Administration 2015; Hakeem 2015) shows that the temperature of the North of the northern hemisphere increased between 1601 and 1974, however in late 20th century the temperature returned to normal. The reason could be increased snowfall which could had delayed the snow melting and onset of spring greening. This change is not unexpected as already discussed that warmer planet would increase ocean evaporation and increased precipitation will occur in the form of rain or snow. Another reason could be other environmental factors which have impacted the growth of plants as species respond to a number of factors which may act positively or negatively. One of the most suitable examples to late 20th century warming is the Alaskan white Spruce (*Picea glauca*). Current warming has increased thermal growing period at high latitudes. During the year there are days when plants can grow and increase the primary biological activity and CO_2 sequestration is increased by photosynthesis; consequently water consumption is increased.

8 Soil Carbon Sequestration

The term carbon sequestration implies the ways and means through which atmospheric carbon is transferred into the long lived pools and storing it safely in a way that it may not be reemitted into the atmosphere. It means increase in Soil Organic Carbon (SOC) and soil inorganic carbon (SIC) through judicious practices and better management and use of land. The observed rates of SOC in the ecosystems depend on various factors which include soil texture, soil profile properties, and climate (Armstrong et al. 2003; Grace et al. 1995; West and Post 2002). Prolonged and sustainable management practices can sustain the rates of carbon sequestered over a period of time (Grace et al. 1995; West and Post 2002). All the systems which ensure the enhanced addition of biomass to the soil, cause minimum soil degradation, conserve soil and water, improve soil structure, enhance microbial activity and species diversity and enhance soil fertility contribute towards the SOC sequestration. Mulching, zero tillage, agroforestry, multiple cropping systems and integrated nutrient management in the form of manures, composts, and bio-solids also fall in the same category (Silver et al. 2000). The restorations of degraded soil with intact resilience capacity have more potential of SOC sequestration. The SIC sequestration is low and is accelerated by different biogenic processes and leaching of carbonates into ground water (Nordt et al. 2000; Levy 1984) especially in the soils irrigated with water having low concentrations of carbonates.

9 Impact of Global Warming on Carbon Sequestration

About 5 % of global carbon is stored by soils and vegetation and their contribution of carbon to the atmosphere is about 50 % (Barraclough et al. 2015). Their response to the climate is not clear yet. It is expected that the processes (loss by respiration and gain by plants residues) contributing towards the soil carbon concentration will accelerate with increase in temperature (Smith et al. 2008). Bond-Lamberty and Thomson (2010) have confirmed an increase in soil respiration over time with the increase in air temperature. The most important and a bit less certain is that these two opposing processes will show changed behavior under warm climate. If the losses of soil carbon increase through respiration more quickly as compared to carbon returns through plant debris, a positive feedback can be drawn on impact of climate change on carbon sequestration (Barraclough et al. 2015). The determination and calculation of changes in soil carbon pool over a period of time can provide an undeniable proof on the balance between gains and losses.

Determining small changes against a longer and different background is challenging because the separation of effects caused by land-use from those caused by climate change are very difficult. A major study that let the scientists to link these changes was conducted by National Soil Inventory of England and Wales (NSI) who have reported large decrease in soil carbon during periods between 1978–1983 and 1995–2005 (Bellamy et al. 2005). However Emmet et al. (2010) reported that the changes suggested by NSI study were unrelated to climate change and even other studies have reported no significant changes in soil carbon over times (Tomlinson and Milne 2006; Barraclough et al. 2015).

An alternative method to study the soil carbon concentration over time was adopted by Fantappie et al. (2011) in which they used ‘space-for-time substitution’ in which changes in carbon across climatic gradients at one time were used to predict carbon under a future climate. Similar models were used by Barraclough et al. (2015) in a combined form to derive regression models between soil carbon concentrations and mean annual temperature and rainfall for each of the 11 land uses reported by Bellamy et al. (2005). They also concluded that their findings were not consistent with Bellamy et al. (2005) altogether. The reported changes were more related with the changes in land-use and reduction in carbon returns from grazing animals. They estimated that only 9–22 % changes can be attributed to climate and indirect temperature related mechanisms could be responsible for these changes.

10 Carbon Sequestration and Sustainability

The world agriculture and degraded soil have 50–66 % sink capacity of carbon loss. Soil management, rainfall, farming systems, soil structure, texture, and temperature are the properties on which soil organic carbon sequestration depends (Lal 2004; Hakeem et al. 2014). The strategies recommended by scientists to increase soil carbon pool include zero tillage, cover crops, soil restoration, reforestation, manuring, soil fertility management, sludge application, water conservation, improved grazing, judicious harvesting and efficient irrigation. An additional yield of crops (up to 20 %) can be achieved by adding one ton of carbon to soil carbon pool. It will enhance food security and will offset the fossil fuel emission by 0.4–1.2 giga tons (Gt) of carbon per year which is equivalent to 5–15 % of the global fossil fuel emission (Sartaj et al. 2016).

The atmospheric and biotic carbon pools are 3.3 times and 4.5 times less than the soil organic carbon (SOC) pool. The SOC exists in the form of dynamic equilibrium between gains and losses. The conversion of SOC from organic to inorganic pool causes severe depletion in the soil. The depletion increases with increased degradation of soil. This depletion enhances when the output of carbon exceeds the input. Some soils have lost as much as 20–80 % of their carbon to the atmosphere. The decrease in SOC may degrade soil quality, productivity, soil ecology and water quality. The emission of the carbon to atmosphere increased with the passage of time and this was 270 ± 30 Gt from fossil fuels and 136 ± 55 Gt from terrestrial ecosystem between 1850 and 1998 (Lal 2004).

11 Soil Carbon Sequestration and Climate Change

The estimates of total carbon sequestration capacity of soil are variable, the range starts from 0.4 to 0.6 Gt C per year (Sauerbeck 2001) and ends at 0.6–1.2 Gt C per year (Lal 2003a, b) and the potential is finite in time and capacity. Until the alleviation of the fossil fuels take effect the C sequestration has bought us time (Sartaj et al. 2016). Some of the main issues related with carbon sequestration in agricultural ecosystem are discussed.

11.1 Agricultural Chemicals

Most of the practices used in agriculture involve C-based inputs. It takes 0.86 kg C kg^{-1} N, 0.17 kg C kg^{-1} P_2O_5, 0.12 kg C kg^{-1} K_2O, 0.36 kg C kg^{-1} lime, 4.7 kg C kg^{-1} of herbicides, 5.2 kg C kg^{-1} of fungicides, 4.9 kg C kg^{-1} of insecticides (Lal 2004) and 150 kg C ha^{-1} for pumping. Similarly, for enhancing use efficiency and mineralizing losses, the wise use of C-based inputs is necessary, nevertheless, the inputs are needed for carbon sequestration but they are mandatory for food production and ensuring sustainability of soil and water.

11.2 Essential Nutrients

Carbon is one of the major essential nutrients and plants cannot complete their life cycle without it (Lal 2004). For the sequestration of 1 Gt of carbon in the soil it would require 80 Mt of N, 20 Mt of P and 15 Mt of K as compared to global fertilizer use which was 136 Mt in 2000 (IFDC 2000). However, there are other sources of carbon sequestration i.e. biological nitrogen fixation, recycling from subsoil aerial decomposition, use of bio solids and crop residues. Lal (2004) has reported that one ton of cereal residue can contribute 12–20 kg of N, 1–4 kg of P, 7–30 kg of K, 4–8 kg of Ca and 2–4 kg Mg. If the residues produced are incorporated into soil (3 Gt) instead of removal for fuel and other uses, would sequester C and improve soil quality. The same crop residues may be used for obtaining biofuel [ethanol or energy (H_2)]. This residue may be used to sequester carbon for the production of biofuel which has enormous economic value.

11.3 Soil Degradation and Deposition

Most of the erosional processes (wind or water) preferentially remove SOC from the sediments and is redistributed over the landscape or re-deposited in the depression sites and aquatic ecosystems. During the processes the C may be buried but most of it is emitted into the atmosphere in the form of CO_2 through mineralization or CH_4 through methanogenesis. The intensity of buried C may vary from 0.4–0.6 Gt C per year as compared to re-emitted which is 0.8–1.2 Gt C per year (Lal 2003b). For sustainable agricultural productivity and land use, effective soil erosion control is essential.

11.4 Better Farming Practices

The annual nutrient losses in sub Saharan Africa due to low inputs is estimated to be 40 kg of NPK ha^{-1} in cultivated land (Sanchez 2002). The effect of SOC mining is similar to that of fossil fuel combustion. Therefore, the better farm management practices must increase SOC pool and enhance fertility which would ultimately lead to increased crop yield and soil quality.

11.5 Social Aspects

For trading carbon credits, its commodification is very important. In Europe carbon trading markets were established in 2002 (Johnson and Heinen 2004). Currently, the low prices of SOC may be increased with regulations and emission caps. In the European Union countries for the concept of SOC credits to make a routine matter as a part of the solutions to mitigate climate change the ability exists to measure short term changes in SOC (Lal et al. 2001), but the need of the hour is to base price of soil C on off site and on site societal benefits otherwise the undervaluing of soil C may lead to tragedy of the commons (Lal 2004).

11.6 Water and Carbon Cycle

Resources of fresh renewable water are decreasing very rapidly. The data shows 56 % increase in cereal production between 1997 and 2050 on ever shrinking land area with less available water (Lal 2004; Rosegrant and Cline 2003). Thus it is very important to develop a link between hydrologic and carbon cycles. This may be achieved by conservation of water resources, improving agronomic yield of the crop and carbon sequestration. The stocks of SOC in rain-fed region can be increased by water conservation, increasing water use efficiency, judicious water harvesting and farming systems. In dry land SOC stocks may be enhanced by zero tillage farming to manage drought: a real win-win situation (Lal et al. 2004).

11.7 Global Warming and Soil Carbon Sequestration

Global warming is a global issue and century-scale problem and soil C sequestration is a separate but related issue having its own benefits of improving water quality, increasing soil productivity, restoring ecosystems and degraded soils. Keeping fossil fuel emission on aside achievable SOC potential provides multiple societal benefits. Moreover, soil carbon sequestration plays a bridging role among three global issues i.e. climate change, desertification and biodiversity.

11.8 Greenhouse Gases

Soil capacity to oxidise CH_4 is increased by enhancing SOC pools. This is a special case under zero tillage farming system (Six et al. 2002). It may enhance emission of N_2O (Smith et al. 2001). These fluxes of CH_4 and N_2O can alter the CO_2 mitigation potential of soil management practices and must be taken care of along with SOC sequestration.

11.9 Tropical Soils

Tropical soils are severely degraded and depleted and have high carbon sink capacity and low rate of carbon sequestration. Since these soils have low crop yields so they need more attention for improvement of soil quality than the soils of high latitude. This improvement is more challenging because of poorly developed infra structures weak institutions and resource-poor agricultural systems. Such lands needs soil restorative policies for the mitigation of soil degrading trends.

11.10 Permanence

Soil carbon sequestration is environment friendly, cost effective, natural process and sequestered carbon remains in soils until recommended management practices like zero till farming and restorative land use are followed. The soil sink capacity and the permanence are related to many physical factors like clay content, mineralogy, temperature regimes, structural stability and ability to form and retain stable micro aggregates.

12 Food Security and Soil Carbon Sequestration

China, Central and South Asia, the Andrian region, the Caribbean and the acidic savannahs of South America (SSA) are the hot spots of global soil degradation and priority area for soil restoration and carbon sequestration. In these regions complete crop residue removal for fuel and fodder is a general norm and depletion of SOC pools from the root vicinity has affected soil productivity very badly. This is simply the revengeful attitude of the poor farmers that they have passed on their sufferings to the soil. They cultivate marginally fit soils with limited resources and get marginal output and live in poverty. The SOC is a source of soil fertility and production in the farming systems of SSA whose contribution is only 2.5 % of the chemical fertilizers consumed and 2 % of the world's arable and irrigated land area. Both of these factors are essential for SOC sequestration. In extremely degraded soils the benefit of recommended management practices cannot be realized in true spirit. An optimum concentration of SOC stock in the soil is needed to decrease the risks of erosion, hold water and nutrients improve tilth and soil structure and be a source of energy for living microorganism in the soil. The SOC acts as a bio-membrane that filters pollutants, provides oxygen in the coastal ecosystems, decreases sediments load in the rivers, degrades contaminants and plays significant role as a sink for atmospheric CO_2 and $CH_{4.}$ The crop productivity increases by addition of fertilizers along with incorporation of crop residues in SSA (Pieri 1986) in the form of mulch (Yamoah et al. 2002).

Even in high-input commercial crops, increase in SOC may enhance crop yield (Bauer and Black 1994) especially in severely degraded soils (Johnston 1986) where it has been depleted. It is reported that an increase of 1 ton of SOC in cereal wheat, yields by 27 kg ha^{-1} in America (Bauer and Black 1994) and by 40 kg ha^{-1} in semi-arid parts of Argentina (Diaz-Zorita et al. 2002), 17 kg ha^{-1} of maize in Thailand (Petchawee and Chaitep 1995) 6 kg ha^{-1} of wheat and 3 kg ha^{-1} of maize in alluvial soils of northern India (Kanchikerimath and Singh 2001). For sustainable high yield, high SOC is necessary which improves nutrient and water use efficiency and microbial activity in the soil. For tropical soils the critical value of SOC is 1.1 % (Aune and Lal 1997) and increasing its concentration from a low level of 0.1–0.2 % to the critical value is a major challenge for tropical ecosystems. Nevertheless, a sharp decline in the SOC stock in SSA or anywhere in the world must be revised in order to ensure advance food security. In Kenya, a study was carried out for 18 years, the results revealed that the yield of maize and bean was 1.4 ton ha^{-1} per year in the control (without external inputs) and 6 tons ha^{-1} per year was recorded when stover was retained in the soil and fertilizer and manures were applied. The SOC pool recorded in the same field up to 15 cm depth were 2.3–6 tons ha^{-1} and 28.7 tons ha^{-1}, respectively (Kapkiyai et al. 1999). This sort of management is needed at global level to ensure food security. It is need of the hour that vicious circle of decreasing productivity, declining SOC pools and lower per hectare yield must be broken by improving soil health through SOC sequestration. This will help to free humanity from perpetuating poverty, hunger, substandard living and malnutrition.

13 Climate Change and Biodiversity

These days the researchers have focused their research on the predictions of responses of biodiversity to climate change (Dawson et al. 2011; McMahon et al. 2011; Beaumont et al. 2011; Salamin et al. 2010; Pereira et al. 2010; Bellard et al. 2012; Hakeem 2015). The response of biodiversity to climate change plays significant role in planning and alteration of the thinking of scientists to stop the biological changes due to climate change and decrease the climate change impacts on biodiversity (Parmesan et al. 2011). Currently the research suggests that there is relatively little evidence of the extinctions of species due to the impact of climate change. However, it is predicted that natural habitats of different species could be destroyed due to climate change over the next few decades (Leadley et al. 2010). However, to get the clear picture of future of the biodiversity is difficult because of the variability and the multiplicity of approaches. Therefore, it is extremely needed to review our present understanding of the effects of climate change on the future of biodiversity.

14 Impact of Climate Change on Biodiversity

Bellard et al. (2012) and Parmesan (2006) have reviewed that various components of climate change could affect the biodiversity. Climate change can decrease genetic diversity of populations due to quick migration and directional selection which may in turn impact changes in ecosystem resilience and functioning (Botkin et al. 2007; Meyers and Bull 2002). However, the focus of recent research is on organizational levels and only a little work has been done on the genetic effects of climate change and a very few number of species have been explored.

Beyond this, the web of interactions at community level is modified by various effects on population (Gilman et al. 2010; Walther 2010). In fact the species affected by climate change also affect the other species which rely on them. A study carried out in 2004 on interspecific systems of pollinators and parasites showed that 6300 species are facing the threat of extinctions because of the extinction of those species on which these species depend (Koh et al. 2004). Furthermore, for many species the initial impact of climate change may be attributed through effects on synchrony with species, habitat and food requirements (Kiers et al. 2010). The climate change has induced phonological shifts in pollinating insects and flowering plants which have caused a mismatch between pollinating insect population and flowering plants which has caused extinction of both pollinators and plant populations (Rafferty and Rafferty and Ives 2010). Other changes of interspecific relationships like with predator prey, parasites/host or competitors or mutualists have also changed the functioning of ecosystems and structure of community (Yang and Rudolf 2010).

Climate change may induce variation in plant communities at the higher degrees of biodiversity which are expected to affect biome integrity. It has been forecasted by the Millennium Ecosystem Assessment (MES) that 5–20 % shifts for Earth's terrestrial ecosystems will take place, in particular in the cool conifer forests, savannahs and boreal forests, tundra and shrub land (Sala et al. 2005). Special concerns have been raised for the 'tipping points' where irreversible shifts in biomass may take place in the ecosystems thresholds (Bellard et al. 2012).

Lapola et al. (2009)) have reported that the potential future biomes distribution in tropical regions of South America may change and tropical savannah may replace Amazonian rainforests. Similarly alpine and boreal forests at higher altitudes and latitudes may expand northwards towards more height at the expense of low stature alpine and tundra (Alo and Wang 2008). Rise in temperature and decrease in rainfall may case drying of lakes in Africa (Campbell et al. 2009). Oceans may become more acidic and warm which may destroy tropical coral reefs at large scale (Hoegh-Guldberg et al. 2007). The impact of climate change could be more severe for genetic and specific diversity for ecosystem in services, whose extreme form of decrease of fitness may be extinction of species. To cope with these adverse effects the biodiversity may adopt various mechanisms.

15 Response of Biodiversity to Climate Change

Because of climate change in a given region species may no longer be adapted to the environmental conditions and may fall outside of their climate niche. For survival of the species, populations or individuals must develop adaptive measures of various types which may be provided by two categories i.e. mechanisms and responses (Bellard et al. 2012).

15.1 Mechanisms

There are two mechanisms i.e. genetic and plastic. In genetic mechanisms species may adapt genetically to changing environment by mutation or selection and in plastic mechanisms species are provided with short term responses in behavior, whether or not the species will be able to adopt the mechanisms to cope with changing climate (Lavergne et al. 2010). Whether the adaptations will be motivated by micro-evolution (genetic adoption) or plasticity (short term response) as described by Salamin et al. (2010) and Charmantier et al. (2008). These adaptive means may involve transpacific diversity in physiological, morphological or behavioral traits which may have expression on various time scales within the spatial range of population (Botkin et al. 2007; Chevin et al. 2010). As reported in birds and mammals, the empirical evidence shows that plastic response is more than the genetic contribution (Hoffman and Sgro 2011). On the other side the evolution is very fast (Lavergne et al. 2010) in the case of introduced species and the phenotypic changes have increased the invasive potential (Phillips 2009). Recent work on evolutionary rescue also suggests that rapid evolution by mutation and selection could help species to adopt very severe and rapid environmental changes (Bell and Gonzales 2009).

15.2 Responses

There are three types of responses i.e. spatial, temporal and self. The first two are easily observed and well reputed responses to climate change and self-corresponds to changes which are less obvious physiological and behavioral responses which enable species to adapt to environmental changes in the same space and time paradigms.

In spatial responses species follow specific conditions that they track during adapting period. They generally take place through dispersion however, are not limited to this. Migration to different habitats at micro-habitat or local level can also take place. More than 1000 species have been reported to undergo latitudinal and altitudinal range shifts. This is more common in the case of species with greater dispersal capacities like insects, marine invertebrates and birds (Parmesan 2006) which has lend to the decrease range especially on mountain top and polar species (Ferero-Medina et al. 2010). In this case individuals may shift populations to maintain equilibrium in the environment they are adapted to, at the same time they may not be adapted to the other abiotic conditions such as novel biotic interactions or photoperiod (Visser 2008) in such cases micro-evolution or genetic mechanism may be required for persistence.

The individual species also respond to a climate change through shifts in time period on seasonal or daily basis. These are cyclic variations which take place over a period of time during one year. The best example in this case is temperature that varies on daily or yearly basis. The 20th century global warming has caused changes in the seasons of flowering, fruiting in plants and seasonal migration in birds (Parmesan 2006; Charmantier et al. 2008). The data shows that for last 50 years the phenological events in a wide range of species have been shifted to 5.1 days earlier per decade (Parmesan 2006). These variations help those species to maintain synchrony with changing abiotic factors. However, there could be some disruption due to increased asynchrony in insect-plant or predator prey system which could be a cause of species extinction. The third response of the species to climate change could be by adapting themselves to new conditions and do not track new optional environment in space and time. Unlike spatial, temporal changes are known *in situ* changes since they take place within the species. These may be in the form of physiological alterations that lead to environmental adaptations or changes in behavior of their food, energy and activity. Such changes are not very obvious like changes in time and space and have been reported during the 20th century climate change. For example in many ecosystems changes in growth, locomotion, reproduction and sex determination are temperature sensitive (Tewksbury et al. 2008). This is not true in all the cases like for many plastic phenotypic traits, in extreme climate change should reach a physiological limit. For instance metabolic rate and body size cannot increase or decrease indefinitely under prolonged climate change (Chevin et al. 2010). For such cases, to cope with climate change, strong genotypic selection is required because their spatial and temporal frames does not change hence limit the alterations of interspecific relationship.

Failure of species in any of the mechanisms or responses will lead their population to face extinction on local or global scale. Since there are so many responses for species to adapt to the climate change, therefore only a few taxa of them went extinct due to climate change during past century (Botkin et al. 2007). This is enough to dilute the temper catastrophic predictions about the possible effect of climate change on biodiversity. However, many populations responded inadequately to counter the quickly changing climate, moreover unlike the past the populations of living organisms have to manage to cope with additional threatening factors which may affect them, in synergy with climate change. Since today the world is facing undeniable facts of biodiversity crisis, the number of endangered species has been increasing with time. Some of the facts are narrated below:

16 Climate Change Impact on Agriculture

Agriculture is an important sector of world's economy. It provides as much of our food through crops, livestock and sea food. Its contribution towards economy is in trillion dollars. Livestock, agriculture and fisheries are dependent on specific temperature. It is very difficult to understand the overall impact of climate change on food supply. Increase in CO_2 and temperature can affect some crops positively in some cases, however, its effects on soil health, nutritional level and water availability may also be considered (EPA 2015). Rainfall frequency, floods and droughts could pose serious challenges for the farming communities. At the same time hot weather temperature may alter the habitats ranges and productivity of many fish and shell fish species and could destroy ecosystems. If seen holistically, changes in climate could create more problems for growing crops, raising animals and fish in places as was done in the past. The effects of climate change must be considered along with other allied factors which may affect agricultural practices and technology (Hakeem 2015).

Crop growth in the world has significant effects on the food supply of the world populations especially in US. According to an estimate about 30 % of the wheat, corn and rice produced in US are exported in the global market (US Census Bureau 2011). Variations in the CO_2 concentrations, temperature and rainfall could affect the yield of these crops adversely. For example hot/warm weather may cause quick growth of crops and could reduce yield because the crops grow faster under warmer temperature, however, the time required for grain development would be decreased and yields would be low (USGCRP 2009).

17 Impact of Climate Change on Fisheries

Fish, across the world face many types of stresses which include water pollution, over fishing, heating of oceans. Climate change is worsening these changes and could lead to significant impacts. For instance the range of many fish species may change as several species of fish has particular range of temperature at which they can survive. One of the examples is cod fish found in the North Atlantic thrives best at temperature below 54 °F (EPA 2015). And their reproduction is even reduced when sea bottom temperature is above 47 °F. During the current century this temperature is expected to increase both thresholds. Several marine species are expected to move to colder areas lakes and streams or move to North world in the ocean which may lead to a new competition with new species over food and resources. In warm water some disease may affect the species more than in cold water because in warm water these are more prevalent, as in case of lobsters in New England. Similarly, variation in temperature and season could affect the migration and reproduction periods (CCSP 2008a, b). Many aspects of aquatic life are controlled by seasons for example the warm water in North West has affected the life cycles of salmon and it has become more vulnerable to disease (CCSP 2008a, b), which has caused a large decline in salmon population (Field et al. 2007).

In addition, the increase in CO_2 concentration is causing the acidification of oceans which are affecting shell fish by weakening shells made up of calcium. The acidity may destroy the structures of fish and shell fish ecosystem upon which they rely.

18 Influence of Climate Change on Crop Productivity

For the last several decades, the trends of climate changes in the world's agricultural zones have been very quick and obvious changes in the CO_2 and ozone (O_3) concentrations have been recorded. The actual changes that will occur due to rise in CO_2 concentrations and their influence on climate have raised questions about the security of food. One of them is whether the overall productivity of world's crops will be affected or not. It is estimated that for the next few decades, the global crop yields will increase by 1.8 % due to increase in CO_2 trends (Lobell and Gourdgi 2012) and rise in temperature will decrease yield by 1.5 % per decade. The main factors that will contribute towards this decline include higher O_3 and greater precipitation.

The global food security will be shaped by many factors which include rate of human population, disease, dietary preferences, income growth and distribution, demand for water and land resources for non-agricultural uses, carbon sequestration and rate of improvements in agricultural productivity. The crop yield factor has a special significance which is define as metric tons of grains produced per hectare of land. Sources of agricultural growth including level of funding for research and development, variation in soil fertility and quality, economics and supply of fertilizers, CO_2 and O_3 concentrations in atmosphere and changes in rainfall and temperature are of multi-faced nature. This information focusses on variations in CO_2 and O_3 levels in agricultural regions and their impacts on crops production. This will give us insight on the part of a full story on crop production which will lead us to full story about the future of global food security. For instance this information has no clues about different ways that global change can affect world's food security via different pathways other than agricultural productivity i.e. rate of income growth or influences on human disease occurrences.

19 Climate Changing Trends in the World's Cropping Areas

The data on observed trends, over the past several decades show that air temperature has been increasing in the major cereal cropping areas in the world. Lobell and Gourdji (2012) have reported linear trends in minimum and maximum temperature from 1980 to 2011. Roughly the average trends for maximum and minimum temperature were 0.3 °C and 0.2 °C per decade respectively.

CO_2 concentration in the atmosphere has increased from 278 μL L^{-1} in 1750 to 390 μL L^{-1} in 2000 (Global Carbon Project 2011). Increase in global average troposphere O_3 level is from 15 nL L^{-1} to 35 nL L^{-1} from preindustrial era to the present. Ever increasing pollution can raise this concentration to 100 nL L^{-1} (Wilkinson et al. 2012) which could be damaging to the crops (Oltmans et al. 2006). Solar dimming has also been observed from 1950 to 1980 which is associated with increased pollution and aerosol load (Wild 2012).

The projected trends show that the major factor of global warming will be rise in temperature in the agricultural regions. The data shows average model projected rates of global warming from 2040 to 2060 will be similar to those observed from 1950 to 1980 (Lobell and Gourdji 2012) per decade. However there is no concrete evidence to establish whether minimum temperature will rise faster or slower than maximum temperature (Lobell et al. 2007).

This shows that expected rate of global warming is consistent with the past which may be significantly lower or higher for any one or two decades such as global mean temperature (the average of ocean and land) does not rise for one decade due to 1998 El Naino. Unlikely it is quite possible that we could record 10 years trend of as high as 1 °C in the global mean temperature which will be as much as 2 °C in major agriculture areas of the world because the ocean warms slowly than the land (Easterling and Wehner 2009).

CO_2 concentration is expected to increase in next century because 80 % reduction in its emission is required just to stabilize the current atmospheric levels (Meehl et al. 2007). Up to 2050, 25 μL L^{-1} increases in CO_2 concentration per decade is expected which will raise the overall level to 500 nL L^{-1} by that time (IPCC 2001). In developing countries O_3 precursors emission is expected to raise however, its prediction is difficult due to uncertainty in emission pathways and air pollution control (Cape 2008).

20 Response of Crops to Climate Change

There are primary mechanisms which have effects on agriculture among these are: increasing temperature, severe hydrological cycles, increasing CO_2 concentration in the atmosphere and increase of tropospheric O_3 levels. The mechanisms through which these factors affect crop physiology are discussed below.

Yield of crops is affected by temperature through five ways. First, it enhances growth and development and reduces crop duration, which ultimately leads to reduction in yield (Stone 2001). Second, rates of photosynthesis, respiration and grain filling are affected by temperature without any distinction of C4 or C3 plants (Crafts-Brandner and Salvucci 2002). High temperature during day or night can affect photosynthesis, however, warming during the night increases rate of respiration at the cost of any benefit to photosynthesis. Third, temperature raises the vapor pressure deficit (VPD) between air and leaf, which leads to reduced water use efficiency in the form of more water loss per unit of carbon gain (Ray et al. 2002) and plants close their stomata, reducing photosynthesis and increasing heat related impacts. Fourth, high temperature can damage plant cells directly, reduces spring and autumn frost risk which would lead to frost-free growing season. Contrary to this warming during the critical reproductive periods may induce heat stress, leading to sterility, reduction in yields and risk of crop failure (Teixeira et al. 2013). Fifth, high temperature along with elevated CO_2 in the atmosphere can favor the growth and survival of many pests, insects and diseases in agricultural crops (Ziska et al. 2011).

Increased agricultural droughts will cause water stress in crops which will be harmful especially during the reproductive periods of cereal crops (Hatfield et al. 2011). Alterations in the timing of the rainy season may compel the farmers to shift sowing times or more intense rains will result into flooding and water logging and damage crop production (Lobell and Gourdji 2012). Unlike temperature increase in atmosphere CO_2 levels has some positive effects on crops like fertilization effect of CO_2 in C_3 crops by alleviating photosynthesis pathways. It also increases water use efficiency by decreasing stomatal conductance in C3 and C4 plants (Ainsworth and Long 2005). Fifteen percent increase in yields in C3 plants is expected by raised CO_2 concentration. However, it is also expected that CO_2 fertilization will decrease nutritional quality of crops through decreased nitrate assimilation and lower protein content in harvestable yield (Taub et al. 2008).

Tropospheric O_3 is formed when air pollutants like methane, carbon monoxide and nitrogen oxides react with hydroxyl radicals and causes oxidative damage to photosynthetic machinery in the plants (Wilkinson et al. 2012). These pollutants are found in abundance in the agricultural regions across the globe (Van Dingenen et al. 2009). There are possibilities of interactive effect of CO_2 and O_3 which may reduce the damage caused by O_3 through reduced stomatal conductance. It will reduce damage caused by O_3 uptake by maintaining biomass production (McKee et al. 2000). This has raised a concern about the development of new crop varieties in cereals such as increased stomatal conductance has been induced by breeders to support the fact that higher respiration fluxes are related to increased photosynthetic rate and ultimately to yield (Reynolds et al. 1994) whereas higher stomatal conductance means more uptake of O_3 and vulnerability to sterility and reduced yield (Biswas et al. 2008).

The facts discussed here are not always conclusive because they may vary from region to region and cannot be applied across the world to estimate the response of crop production to changing global climate.

21 Climate Change and Future Strategies for Agricultural Crops Production

With the same or less available land and water resources, 56 % increase in cereal production is estimated by 2050 to feed the population (Lobell et al. 2012). Natural calamities like devastating rains and droughts are predicted to increase (Beddington et al. 2012; Hakeem 2015). Warming trends are expected to decrease global yield of agricultural crops by 1.5 % per decade.

The scientists have been working to revitalize sustainable increase in yield with fewer resources and several frameworks like ecological intensification, evergreen revolution and sustainable intensification have been suggested in the past (Cassman 1999a, b; Swaminathan 2000; Fan et al. 2012). Here a question arises that how can we achieve the objective of increased yield while having several constraints (land and water availability, climate change and environmental degradation).

For this, emphasis must be given to the challenge of applying good governance in modification of suboptimal crop and soil management with the prevailing knowledge of agricultural technologies and introducing advances in crop productivity. Two strategies will help to achieve these goals i) management of integrated crop-soil system which will deal with the existing limitations in the crop cultivars ii) development of new high yielding cultivars which may utilizes less water and nutrients and are more resistant to stresses like drought, pest attack, disease, waterlogging etc. (Fan et al. 2012).

22 Judicious Use and Improvement of Existing Resources and Technologies

Due to CO_2 fertilization the crop yield has increased over the past so many years however, the degradation of existing land and water resources and non-judicious crop management practices are very common. The available evidence shows that there is a huge gap between the total crop potential yield and the average farm yield at the farmers field (Fan et al. 2012). There are several factors which are responsible for this which include no to limited access to technologies, marketing problems and low profitability and poor crop and soil management (Fan et al. 2009). Across the globe, several cost effective and easy to use technologies have been developed and their use at the farmers scale must be emphasized, which can increase yield of grains by 9.2–14.6 % and can improve nitrogen productivity by 10.5–18.5 %. Split use of nitrogen, and changes in transplanting patterns have enhanced yield of rice up to 22 % in China (Fan et al. 2009). Similarly, water saving practices like alternate wetting and drying, irrigation for rice can increase rice yield (Davies et al. 2010). Other techniques for example mulching, deficit watering for upland crops and alternate furrow irrigation in maize have also been reported to increase yield (Yang and Zhang et al. 2010; Wang et al. 2009b). Decrease in emission of greenhouse gases can be achieved by adopting nitrogen management practices i.e. N_2O and CO_2 (Huang and Tang 2010).

For the adoption of new technologies, it must be ensured that all farmers have access and purchasing power; for this purpose economic incentives can play important role. Farming subsidies may be beneficial to motivate farmers to adopt new technologies and suitable management practices.

23 Innovations in Crop Production

For ensuring food security greater improvement and innovation in crop production must be carried out by developing a multidisciplinary approach including the joint ventures of plant scientists, soil scientist, agronomists, social scientist, agroecologists, plant breeders and microbiologists. This approach will help to understand coupling mechanisms that exist between climate and crops, soil and plant ecology and plant biology and various rhizospheric components and their management (Yang and Zhang 2010). For this purpose three points must be emphasized i) integration of soil fertility and nutrients management with intensive cultivation systems ii) utilization of different nutrient resources must be integrated with supply to the crop needs iii) take all possible measures to maintain soil fertility and quality (Zhang et al. 2011).

Genetic improvement in the crop cultivars with improved yield potential through conventional and genetic engineering will be critical for future food security (Foulkes et al. 2010). Yield potential has been defined as the yield of a crop under optimum growing conditions (Evans 1996). When crop reaches to 80 % of its potential it becomes very difficult to improve it on sustainable basis through conventional practices. It suggests that at this stage the improvement of a crop will depend on the improvement of yield potential. Here we need to breed cultivars which have high yield potential, or resource efficient and resistant to biotic and abiotic stresses (Morison et al. 2008). Conventional breeding techniques must be combined with advanced breeding methods such as genetic engineering and marker based selection. This will help more specific selection of required germplasm among multiple traits and breeding cycle will be fast. This technology will help to achieve the challenge of identification of the suitable genes needed for breeding, their incorporation in to elite genotypes and evaluation in the field trials, adopting new genetically modified crops and increasing consumer's acceptance (Zhang et al. 2007).

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