



Review Article

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Climate Change vs Soil Management: Challenges, Opportunities and Policies

B B Mishra^{1*}, Richa Roy², Sheleme Beyene³ and Kibebew Kibret⁴

¹Bihar Agricultural University, India

²TNB College, India

³Hawassa University, Ethiopia

⁴Haremaya University, Ethiopia

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***Corresponding author:** B B Mishra, Bihar Agricultural University, Sabour, Bhagalpur 813210, India.

Abstract

The climate change is an outcome of a set of complex phenomenon that could be enlisted in terms of both natural and man-made components or spectra in order to develop a strategic management planning for mitigation, since efforts in isolation cannot be sustainable. The man-made components imposing challenges may be minimized even on site-specific basis, if efforts are made systematically. An efficient adoption of conservation agriculture integrating with organic farming by providing locally available organic inputs as well as effective but beneficial soil microorganisms could be a reliable but partial solution to minimize the earth warming on site-specific basis. Soil being a powerful sink for GHGs (particularly CO₂) needs to be investigated critically but continually. Shrinkage of land due to non-farming activities is a disastrous consequence favouring the speedy rate of climate change. Such shrinkage is irreversible causing complete stoppage of greenery and vegetation besides ecological imbalance, which calls for immediate legal ban following some alternative solutions by the government. At this juncture, it is wise to trust that the more mature the science, the more confident we can be towards mitigation of overall global climate change. If climate is changing, land would automatically be changed besides manifestation of other changes. A new soil group proposed as Immobisols in Ethiopia may be a good example to understand the soil based hidden facts of carbon sequestration. By restoring soil health through conservation agriculture (as innovated by imposing "Soil Carbon Trade") following a strict policy to minimize the extent of land shrinkage (both rural and urban), a strong strategic base could be developed on way to maximize carbon sequestration as well as capturing the increasing trend of atmospheric temperature to its desired limit. Besides, global necessity to insure clean energies generation by minimizing coal and fuel burning, petroleum consumption and irreversible uses through non-farming activities of lands is inevitable. By and large, the world has to be seriously aware of technological generation for utilizable transformation of solar energy in different fields of interest including second green revolution.

Keywords: Climate change; Land shrinkage; Conservation agriculture; Immobisols; Soil C-trade; Second green revolution

Introduction

The Paris climate conference has set a critical goal to limit the global warming to 1.5 degrees Celsius as against the threshold of 2 degrees as speculated before. The disastrous consequences within the limit between 1.5 and 2.0 degree would signify the extent of danger that everyone on the earth is going to encounter. Even the target of 1.5 degree Celsius fixed during the conference needs to be authenticated for being realistic on global basis. Today's human population stands at a critical zone of climate change. The climate may be the average of weather condition, but in true sense, it is the product of multi-component interactions associated with interplanetary and extra-terrestrial environments, which form a wide range or sequence covering the spectrum for common goal of climate change. Altogether six spectra viz.

planetary in physical state, EM-nuclear, chemical, biological, pedogenic and anthropogenic spectra are considered viable [1]. Out of many such interaction effects, human interferences as well as pedogenic exploitation do play vital role that could be manageable by integrating the activities in line with desired climate equilibrating with livelihood. Soil is the lowest boundary of the entire earth's atmosphere, excluding the part covered by ocean, with immense carbon storing potential that undergoes interactions with incoming radiation including background nuclear counts as well as chemical, biological, physical and anthropogenic interferences. Soil is the natural foundation for survival and nourishment of infinite lives including human beings. Vink [2] opined that solar radiation coming to the land

area is of the order of $28,000 \times 10^{12}$ watts per year. Starr et al. [3] stated that hydropower produces a maximum of 3×10^{12} watts per year. Sys et al. [4] concluded that 95 per cent of the energy input of the world comes from solar radiation. It is further argued by Sys et al. [4] that nearly half of such incoming solar radiation is directly transformed to heat, remaining about 23 per cent consumed in energizing the evaporation and precipitation and hardly 0.02 per cent (5.6×10^{12} watt per year) is used in photosynthesis.

Soil health indicators are a composite set of measurable physical, chemical and biological attributes which relate to functional soil processes and can be used to evaluate soil health status, as affected by management and climate change attributes. A study of the long-term trend in surface air temperatures in India by Hingane et al. [5] indicated an increase in mean annual temperature of 0.4°C over the past century. The Soil health in relation to climate change may take into account the impacts of localized status of global warming index including existing levels of atmospheric green house gases, increased temperature, changing trend of frequency, intensity and distribution of rainfall, flood and drought events and atmospheric nitrogen deposition on soil chemical, physical, biological and fertility behaviours. But, the complexity associated with interactive effects causing the climate change is not fully understood and needs a comprehensive interpretation to arrive at a sound but logical prediction. It is further to note that the soil health is often used synonymously as soil quality in soil science text books, but soil health provides better opportunities to emphasize both soil biodiversity as well as agro-ecology together in order to enable the soil as a dynamic living entity of nature.

If climate is changing, land is automatically liable to change, since climate is the integral part of the land. Under such critical situation, soil being the second integral part of climate could only be the hope to mitigate the extent of climate change as much as possible. Obviously, soil must be considered as a reservoir to store green house gases. Truly, as Janseens et al. [6] stated, the soil is one of the important sources as well as sinks of greenhouse gases (GHGs) causing global warming and climate change. It

contributes about 20% to the total emission of carbon dioxide through soil respiration and root respiration, 12% of methane and 60% of anthropogenic nitrous oxide emissions [7]. It is presumed that the global warming may influence global carbon cycle besides distorting the structure and function of ecosystem. The GHGs virtually trap the outgoing IR radiation from the earth's surface and raise the temperature of the atmosphere [8]. The global mean annual temperature at the end of 20th century has increased by $0.4\text{-}0.70^{\circ}\text{C}$ above the values recorded at the end of 19th century. The past 50 years have indicated an increasing trend in temperature at 0.13°C per decade, though this trend is much higher and according to IPCC [7], this trend of rise in temperature may be between 1.1 and 6.4°C by the end of 21st century. Obviously, the issue is very alarming. The global climate change cannot be studied in isolation. It is an issue to be discussed on integrated basis taking six different spectra into consideration as opined by Mishra & Richa [9].

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Green House Gases (GHSs)

Table 1: Greenhouse gases with salient features.

| S. No | GHG | Nature | Mean lifetime | 100-year Global warming |
|-------|-------------------|--|---------------------------------|---|
| 1 | Carbon dioxide | Released through burning of fossil fuels (oil, natural gas, and coal), solid waste, and trees/wood products besides land use/land cover, deforestation including soil degradation | * | 1 |
| 2 | Methane | Emitted through oil and natural gas as well as coal. also from livestock and agricultural practices (rice), anaerobic decay of organic waste in municipal solid waste landfills. | 12.4 years | 28-36 |
| 3 | Nitrous oxide | Emitted as caused by agricultural and industrial activities, combustion of fossil fuels and solid waste. | 121 years | 265-298 |
| 4 | Fluorinated gases | Mixed gases containing fluorine with hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride among other chemicals and emitted during industrial processes besides commercial and household uses, but never naturally as in ozone-depleting substances like CFC (chlorofluorocarbon). | Few weeks to thousands of years | Varies (Maximum in sulphur hexfluoride at 23,500) |

The drastic imbalance in anthropogenic activities has led to increasing trend in emission of carbon dioxide, methane and nitrous oxide in the atmosphere. These three gases are collectively known as “green house gases”, although industrial Fluorinated gases are also included (Table 1). The rate of carbon mineralization is high in the tropics due to high temperature and low humification efficiency [10]. Emissions of carbon dioxide (CO₂) from farm operations and for the production of various farm inputs were calculated using the values given by Pathak and Wassmann [11]. Minimizing the carbon dioxide emission from soil and agriculture by increasing carbon sequestration in soil implies the carbon storage as soil organic matter [12,13]. Addition of about 10 Mg FYM ha⁻¹ was reported to sequester 0.33 Mg carbon ha⁻¹ yr⁻¹ [8]. Optimal supply of nutrients in soil may enhance biomass production and soil organic carbon content. However, the use of organic manure and compost enhances the soil organic carbon pool more than application of the same amount of nutrients as inorganic fertilizers. It is almost established that the long-term manure application increases the soil organic carbon (SOC) pool, which does sequester the CO₂. But, the SOC sequestration is a challenge in soils of the tropics and sub-tropics, where resource-poor farmers cannot afford the input of organic manure and crop residues. In India, according to Pathak et al. [8,14], about 335 Mt dung is produced per annum, out of which almost 110 Mt is lost in domestic and other uses and only 225 Mt is left for use in soil and this is only 1/3rd of the FYM demand in soil for C sequestration in Indian context. However, among other sources, municipal solid waste (MSW) in major Indian cities is estimated to be around 40,000 Mg d⁻¹ [8,15]. As Pathak et al. [8] reported, the biodegradable OM in MSW is about 28% by mass and thus the MSW from Indian cities may generate 4.1 Mt carbon yr⁻¹. Besides, India also produces about 500 Mt crop residues per annum, which may be a powerful input for C sequestration, if exploited purposefully. In soil, methane (CH₄) is formed from organic carbon present in soil and C added through organic residues, dead roots and root exudates. Indigenous methane emission was calculated as a function of available C substrate, that is dissolved organic carbon, which in turn is related to SOC (%), bulk density (g cm⁻³), soil depth (cm), crop duration (days) and the rate of decomposition (0.000085 per day) of SOC [11]. Application of fermented manure like biogas slurry instead of unfermented FYM could reduce the CH₄ emission. Similarly, CH₄ emission from ruminants may be reduced by altering the feed composition as stated by Pathak and Wassmann [11]. Nitrous oxide emission (N₂O) is related to the mineralization of organic N (from soil, residues, and manure) into an inorganic pool, which was in turn related to the mineralization of C, addition of inorganic fertilizer as either NH₄⁺ or urea forms and nitrification and denitrification rate (0.0024 kg kg⁻¹). A similar approach has been used in the denitrification and decomposition (DNDC) model for estimating N₂O emission from soil [8]. Agriculture on global basis contributes about 60% of N₂O and 50% of CH₄ emissions [16]. However, soil (38% of

CH₄ + N₂O), rice production (11% of CH₄) and biomass burning (12% of CH₄ + N₂O) are the major sources in agriculture for N₂O and CH₄ emission [17].

Global Warming Potential (GWP)

The balance between incoming and outgoing energy on the earth surface is responsible for temperature variation on the earth. If incoming solar radiation is absorbed on the earth, it gets warm. However, if the same radiation is reflected back to space, the warming situation is negligible. But, if the absorbed radiation is released back to space, there is chance to cool the earth. This simply follows the classical laws of physics, but it remains surrounded by a number of complex factors both natural and man-made. The greenhouse gas ultimately warms up the earth's atmosphere by absorbing the energy as well as declining the rate at which the energy does escape to the atmosphere. The type specific greenhouse gases may vary in warming the earth's atmosphere. So, these gases differ from each other in respect of their ability to absorb the energy and the lifetime of their co-existence in the atmosphere (Table 1). A study of the long-term trend in surface air temperatures in India by Hingane et al. [5] indicated an increase in mean annual temperature of 0.4°C over the past century.

The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Virtually, it is a measure of how much energy the emissions of one ton of a gas will absorb over a given period of time, relative to the emissions of one ton of carbon dioxide. The larger the GWP, the more that a given gas warms the earth compared to carbon dioxide over that time period. The GWP thus refers to an index that compares the strength of different green house gases (GHGs) in raising the temperature of the atmosphere, wherein CO₂ is used as a reference gas to compare the ability of a GHG to trap the atmospheric heat relative to CO₂ [8]. The GHG emissions are thus computed as CO₂ equivalent. A 100-year GWP is standard that is accepted globally on time scale. The GWP of CH₄ and N₂O are significantly higher than of CO₂, since the GWP of CH₄ is 25-times and of N₂O is 298-times higher than CO₂ over a 100 year's time horizon [7]. The GWP of a soil may be calculated using equation as below [7].

$$\text{GWP of a soil (kg CO}_2\text{ equivalent ha}^{-1}\text{)} = \text{CO}_2 + \text{CH}_4 \times 25 + \text{N}_2\text{O} \times 298$$

Natural vs. Man-made Climate Change

The record of our climate dates back hundreds of thousands of years and even more based on interpretation of a number of indirect measures like tree ring, ice core, glacier's height and lengths and ocean sediments besides details of changes in earth's orbit around the sun. This record shows that the climate system varies naturally over a wide range of time scales. In general, climate changes prior to the Industrial Revolution in the 1700s can be explained by natural causes, such as changes in solar

energy, volcanic eruptions, and natural changes in greenhouse gas (GHG) concentrations. However, present trend of climate changes can hardly be considered by natural causes alone.

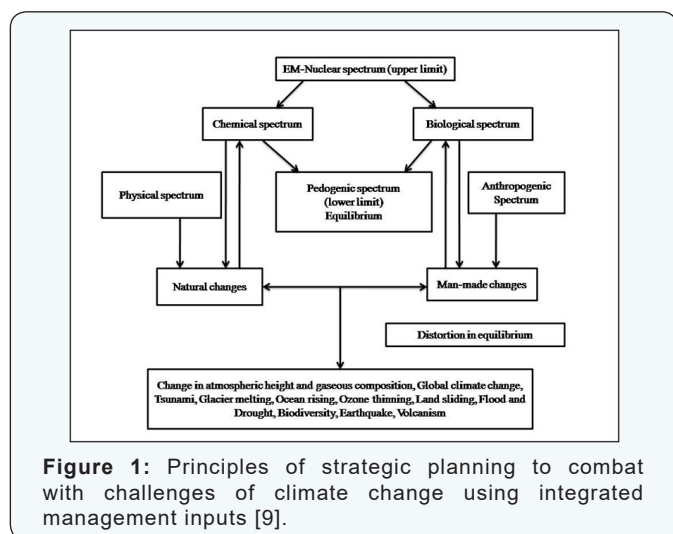


Figure 1: Principles of strategic planning to combat with challenges of climate change using integrated management inputs [9].

The atmosphere is simply the envelope surrounding the earth's lithosphere, wherein six spectra are playing major role in maintaining the equilibrium responsible for a climate. These are physical form and stability of the earth i.e. planetary physical spectrum, electromagnetic-nuclear spectrum besides chemical, biological, pedologic and anthropogenic spectra (Figure 1). The earth's primitive atmosphere was presumed to contain CH₄, H₂, NH₃, N₂, CO, CO₂ and H₂S [18]. As opined by Mishra & Richa [9], a group of physicists may approve and quantify the mode of equilibrium among earth's magnetic field, gravitational matrix and incoming solar radiation that could be congenial to the existence of life on the earth, since life by no means can be the inherent constituent of the earth's system, but simply a by-product as a result of interactions during climate change by itself. This will surely be a breakthrough in modern science. Similarly, fauna and flora including their diversity contribute significantly to balancing the atmospheric load. Besides, human interferences as well as pedogenic disturbances lead to challenge the equilibrium and stability of the earth's atmosphere in a big way. In totality, global climate change is virtually a spontaneous natural process as controlled by planetary and other natural phenomenon. The composition of primitive atmosphere of the earth was entirely different from present day's composition [18].

Interacting nature possessed by soils may be discovered precisely in order to monitor the changes in climate. The upper layer of the atmosphere (exosphere) may be an envelope until the envelope is not disturbed by some means. The challenges with global climate change are natural as well as man-made and the associated impacts are manageable with participatory commitments in a planned way on site specific basis through suitable human intervention, pedogenic exploitation etc. The human beings by way of their mental intelligence have immense potential to re-organize most of accessible natural set-up for self

contentment. The present day speedy technological revolution together with other ill-human treatments with the nature is the consequences of what we see today in climatic scenario. Major human activities resulting into alarming consequences may be as below:

- i. Deforestation, mining, erosion, landslide and bare lands devoid of vegetation.
- ii. Petroleum, coal and wood fuel burning with gas emission.
- iii. Shrinkage (soil sealing) of natural landforms with non-farming activities/construction.
- iv. Loss of biodiversity through hunting, weeding and similar acts of eradication.
- v. Nuclear contamination caused by human interferences.
- vi. Rapidly increasing human population and ill-techniques developed in selfishness.
- vii. Industrial products like CFC through technological up-gradation/generation.
- viii. Decay of organic residues, garbage etc. without recycling.
- ix. Electronic networking damaging the natural stability.
- x. Use of fertilizers, chemicals, insecticides in excess causing toxicity/pollution.
- xi. Large area under rice cultivation causing methane emission.
- xii. Uprooting of orchards and other plantation.
- xiii. Ill-human activities to contaminate/pollute different food, water and air/ecology.

Science is a key to the system to exploit and that too for the welfare of mankind. If man finds something benefitting, he tries to do so without caring for its consequences in the long run. Such habit of a man is the sole cause of disturbances in climatic set-up other than natural causes as stated elsewhere. Can we correct such wrong doings made in past and present by human race? Is it possible to streamline the eco-friendly work culture for men across the globe? Let's look for a new science i.e. science for climate.

Land Shrinkage towards Disastrous Consequences

Imbalanced human population increase and rapid urbanization followed by non-farming uses of land are some examples of land shrinkage for agricultural use. Such shrinkage (sealing) is irreversible causing complete stoppage of greenery and grain production besides ecological imbalance, which calls for immediate legal ban against such practice. For rehabilitation, alternative planning may be executed either in the form of construction of multistory buildings in lands with rock outcrops

and so or similar arrangement on coastal or river bank, since soil cannot be the waste so long as it is a resource. But, the situation with land shrinkage is very alarming and disastrous even in bringing climate changes in particular. Even the young orchards are being destroyed on way to sale the productive lands for construction purposes extensively. He first author (B.B. Mishra) in a book entitled “ 25 Years’ Perspective Plan of Land Use Planning of Bihar, 2000-2025” [19] made a first-hand working plan to restore overall sustainability of soils in Bihar that may also help to maintain a congenial climate.

It is projected that out of total geographical land mass of 328 million hectares in India, only about 182 million hectares (60%) is cultivable. However, in 1988-89, there was 185.14 million hectares of cultivable land, out of which only 45 percent of land was under irrigation. It is further projected that the land area is decreasing faster than population employed on it. Based on a statement appeared in The Times of India on 13th August, 2013, as many as 20 states in India suffer from decline in cultivable land to the tune of 0.79 million hectare during 2007 and 2011 (four years). Such decline is attributed to irreversible shifting of cultivable land for non-farming activities including construction of roads, buildings, industries and many other infrastructural facilities, since these activities and diversions are inevitable for any development programme. However, the government in its National Rehabilitation and Resettlement Policy (NRRP) 2007 suggested measures against ever-declining cultivable land. Earlier, The Economic Times In similar statement on 27th February 2011 indicated the shrinkage of 2.76 million hectares of agricultural land in the last two decades.

Historically, India has moved from being a food deficient land in 1960s to almost a food surplus nation with success in Green Revolution around 1970. However, the continued shrinking trend of productive agricultural land during the last decades is becoming alarming. In terms of employability, almost 57 percent of total work force was employed in agriculture sector in 2001, whereas in 2011, only 54.61 percent is employed causing unemployment stress of 2.39 percent. The central government has formulated the National Policy for Farmers and the National Rehabilitation and Resettlement Policy in 2007 which also envisage prevention or minimization in utilization of agricultural land in non-agriculture activities. But, such land in India has shrunk by around two percent almost within the last two decades. This signifies that India can hardly be respected for being the predominate agrarian country in days to come. Even if we justify that India had produced 169.92 million tonnes of food grain in 1988-89 followed by 234.47 million tonnes food grain in 2008-09 (38% yield increase), the issue of land shrinking is location specific, which is disastrous.

Conservation Agriculture

The easiest way to minimize the challenges of climate change through C-sequestration is to follow the conservation agriculture

(CA) by keeping the land covered with vegetation and/or crop residues round the year with least or zero tillage. The CA follows the principles of restoring the biodiversity and pedo-ecosystem. Selection of site-specific crop rotation based on parametric land evaluation followed by land use suitability identification may be the prerequisite for a given field plot. In this particular agriculture, one suitable cover crop is identified between two main crops based on nature and height of main crops already identified and such exercise needs exhaustive experience with indigenous knowledge and this may enable a soil scientist to work together with farmers in an interactive environment. Then, fix the balanced nutrition to the crops in rotation (including cover crops) based on soil fertility evaluation.

Soil covered with vegetation round the year may buffer the diurnal temperature change and minimize the organic matter decay considerably, thus, creating a congenial environment for C-sequestration. As farmers seek to change from chemical-based conventional farming systems to more sustainable kinds of agriculture i.e. organic farming, which may be adopted in conservation agriculture (CA) successfully, wherein one has to be sincere to use accessible organic sources like (i) crop residues comprising of both shoot and root residues (ii) plant debris in suitable sizes (< 2 mm but larger than 0.053 mm) (iii) humus (decomposed materials less than 0.053 mm that are dominated by molecules stuck to soil minerals) and (iv) compost, FYM, vermicompost and others, which are prepared locally [20]. In CA, farmers should essentially learn, ahead of managing the organic resources, how to sustain soil moisture by managing organic source itself. The amount of plant available water can be determined by two parameters: (i) the lower limit i.e. the amount of water in the soil that plants cannot extract or utilize and (ii) the upper drained limit i.e. the amount of water that can be held against drainage. The difference between the upper and lower limit does define the potential available water holding capacity (PAWC) of a given soil. If this value can be increased even marginally through CA, it will help to sustain or simply maintain or optimize the potential productivity by allowing the soil to retain more water each time that rains. For any given clay content, as organic carbon increases the upper limit, the PAWC of the soil increases further [20]. The amount of carbon in a soil results from the balance between inputs (plant residues or other sources) and losses (microbial decomposition and associated mineralization). Higa & Parr [21], while advancing the concept of “Effective Microorganisms” (EM) rightly stated that the transition from conventional agriculture to organic farming can involve certain risks, such as initially lower yields following the increased pest problems. Once through the transition period, which might take a few years, farmers may find their new farming systems to be stable, productive, manageable and profitable without pesticides.

The soil C sequestration is truly a win-win strategy. It restores degraded soils, enhances biomass production, purifies

surface and ground waters and reduces the rate of enrichment of atmospheric CO₂ by offsetting emissions due to fossil fuel [12,13]. The sustainable production using conservation agriculture may be a win-win-win-win outcomes viz. good for soil, good for livestock, good for human nutrition, good for the environment and good for farmers, but importantly best for mitigation of climate change, although gradually to attain a steady rate, if organic resource is continually applied within the limit of SOM turnover.

Soil Microorganisms

First author in 2013, while proposing the Indian system of soil classification scheme, included a very specific soil group "Microbisols" possessing beneficial and effective soil microorganisms [22]. The ways in which microorganisms have been used over the last few decades to advance the medical technology, human and animal health, food processing, food safety and quality, genetic engineering, environmental protection, agricultural biotechnology and effective treatment of agricultural and municipal wastes provide conceptual and logical inputs for their application in soil based research across the globe. But, while microbial technologies have been applied to various agricultural and environmental constraints with considerable success, they have hardly been accepted widely because of limitations in reliability of impacts. Microorganisms are effective optimum conditions for metabolizing their substrates including moisture, temperature, pH as well as oxygen (whether microorganisms are obligate aerobes or facultative anaerobes). Since microorganisms are useful in eliminating the limitations associated with the use of chemical fertilizers, amendments and pesticides, they may be applied widely particularly in organic farming [23]. Imbalanced environment caused by excessive soil erosion and the associated transport of sediment, chemical fertilizers and pesticides to surface and groundwater besides faulty exploitation of human and animal wastes has caused serious environmental and climatic problems. However, it is well documented that such problems cannot be solved without using microbial methods in agricultural production system [24]. Beneficial microorganisms are those that can fix atmospheric nitrogen, decompose organic wastes and residues, detoxify pesticides, suppress plant diseases and soil-borne pathogens, enhance nutrient cycling and produce bioactive compounds such as vitamins, hormones and enzymes that stimulate plant growth. Soil microorganisms are the major component of biochemical nutrient cycles and global fluxes of CH₄, CO₂ and N. Reports claim that the climate change is already changing the pattern of infectious diseases caused by soil pathogens [7]. The harmful microorganisms are those that can induce plant diseases, stimulate soil-borne pathogens, immobilize nutrients and produce toxic and putrescent substances that adversely affect the plant growth [23]. Selected soil microorganisms mediate the N-cycles, while methanotrophic bacteria help to oxidize methane into CO₂ in presence of oxygen. The high CO₂ concentration in soil accelerates the average growth of a plant and thus allows

sequestering more CO₂. Bacteria and fungi in soil respiration help in organic matter decomposition forming CO₂. Global soils are estimated to contain twice as much C as the earth's atmosphere [7]. It is thus logically emphasized that like many soil groups in the classification schemes, efforts should be made to characterize a soil specific dominantly to beneficial microorganisms effective in farming system and may be designated as Microbisols in respective classification scheme.

Indicators of Climate Change

Indigenous knowledge based on accumulated experience of the farming communities across the globe has been a powerful source to forecast the climatic happenings. In India, the folk poems of Great Ghagh are on everyone's lips to tell about the changing events in weather and climate. But, those poems are not coinciding to the actual climatic happenings of today. This is a strong indicator of deviation in climatic calendar in India. However, such indigenous tools need to be reviewed and tested globally. Until a few years before, incidence of flood in India was centred to only northern states like Bihar and Assam, but the situation now is completely changed and flood occurrence is becoming common to most of the states as of now. This year (2016), almost half of the Indian Territory has suffered from incidence of flood. Water tables beneath the soil are moving down after rain or flood at higher rate followed by manifestation of drought even in flood prone areas. There is severe infestation of pests and diseases not only in crops, but the soils also suffer from pathogens and harmful microorganisms.

Photopedogenesis [25] that refers to interaction of light with rock, soil, moisture and phototrophic microorganisms including soil organic matter may be tested in line with soil-climate chain. The lakes and rivers are drying, ground water levels are moving down and the glaciers are melting. Similarly, soil quality is getting deteriorated, soil water is getting contaminated and air for breathing is not safe. Such changes do have linkage with soil-water-forest chain in a particular eco-system and so with the climate even at micro levels.

Pathak et al. [8] in India developed a strong database on methodologies for assessment and application of climate change impacts and mitigation. Similar accumulated data across the globe may be reviewed on some international yardstick in order to establish the success stories to be utilized for generating useful technologies of relevance.

Soil health indicators are a composite set of measurable physical, chemical and biological attributes which relate to functional soil processes and can be used to evaluate the soil health status as affected by climate change at least on location basis. A study of the long-term trend in surface air temperatures in India by Hingane et al. [5] indicated an increase in mean annual temperature of 0.4°C over the past century. Soil health in relation to climate change may take into account the impacts of localized status of global warming index including existing

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How Much Carbon Can a Soil Sequester?

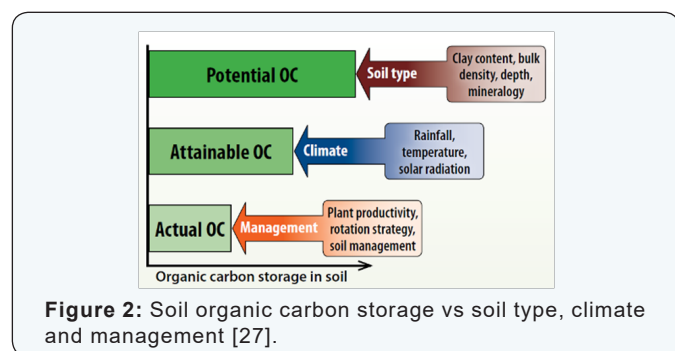


Figure 2: Soil organic carbon storage vs soil type, climate and management [27].

Current interest in carbon sequestration in soil rests on facts of how much organic carbon can virtually be stored in soil. The total organic carbon refers to the amount of carbon in the soil that also relates to the living organisms. By increasing the amount of OC stored in soil, one may improve the soil quality, since the OC contributes to favorable physical, chemical and biological processes in the soil environment. In fact, the amount of organic carbon stored in soil is the sum of inputs to soil through plant and animal residues and losses from soil through decomposition, transformation, erosion and removal through flood or rain water. Increasing the total organic carbon in soil with subsequent reduction of CO₂ emission promotes soil quality for sustainable agriculture. Obviously, the management practices that can maximize plant growth as well as vigor and minimize the losses of organic carbon from soil forms the basis of highest organic carbon storage in soil, wherein soil type forms the basis to decide the maximum capacity to store organic carbon. Without continual inputs of OC, the amount stored in soil will decrease over time because OC is always being decomposed by microorganisms. The process in which losses and gains of organic matter proceed simultaneously is described as turnover and may be defined as the flux of organic matter through a given volume of soil. The turnover time is the amount of carbon in a soil system when equilibrium is reached divided by the annual input of carbon into that system [26]. The off take of OC in crop or plant as well as animal produce is also a loss of OC from soil. Harvested materials such as grain, hay, feed and animal grazing all represent loss of OC including nutrients from the soil. Organic carbon storage in soil is basically a function of associated

components like soil type with defined organic matter turnover, existing climate and management inputs as depicted in Figure 2 [27].

Table 2: Fractions of soil organic matter (SOM) on generalized basis.

| Fraction | Size | Turnover time | Composition |
|----------------------------|---------------------------|-----------------|--|
| Dissolved organic matter | <45 (µm) (in solution) | Minutes to days | Soluble root exudates, sugars & by-products of decomposition, less than 5% of total SOM. |
| Particulate organic matter | 53µm-2mm | 2-50 years | Fresh decomposable plant and animal substances, 2-25% of total SOM. |
| Humus | <53µm | 0s-00s years | Decayed organic compounds, resistant to decomposition, more than 50% of total SOM. |
| Resistant organic matter | <53µm <2mm | 00s-000s years | Inert material, chemically resistant or organic remnants like charcoal, upto 10% of SOM. |

Plant growth generally increases shoot, roots and root exudates with optimal nutrition under sound water use efficiency, but protection against pest and disease. By keeping soil covered with vegetation as well as crop residues or at least growing plants for longer duration by allowing shorter fallow followed by transfer from cropping to pasture or even agro forestry may promote OC stock in soil. Reducing the OM decomposition and erosion, improving soil aggregation and reducing soil compaction are all the precautionary measures to promote OC capture in soils (Table 2). According to Sommer and Bossio [28], the dynamic nature of soil carbon storage and interventions to foster is by and large conditional. Firstly, adoption of SOC-sequestration measures may take time and reasonably such schemes could only be implemented gradually at large-scale. Secondly, if soils are managed as carbon sinks, then SOC will increase only over a limited time, up to the point when a new SOC equilibrium is reached. Thus, SOC sequestration is not a C wedge that could contribute increasingly to mitigate the climate change beyond the defined limitations associated with a soil type. However, restoring or increasing the SOM (Table 2) through efficient management inputs could sustain the soil health, agro-ecosystem and inherent productivity besides potential additional sequestration of SOC. It is commonly assumed that the introduction of soil carbon sequestration measures on agricultural land, such as conservation agriculture, will continue to fix carbon at a constant rate for some decades into the future, but not beyond its capacity. There is no single technology in isolation to stop climate change without integration.

Immobilisols: A proposed Soil Group in Ethiopia

In Ethiopia, the soils derived from basalt and even limestones under sub-temperate climate often show high C: N ratio [29]. Apparently, the soil organic matter is strongly under immobilization processes. High biological activity is indicated by common, fine, open or filled channels or holes called krotovinas. However, termite mounds are seldom noticed in the vicinity of these soils. Ingestion of soils by insects may influence the association and chemical character of inorganic/organic constituents in these soils. Generally, these soils are low in total nitrogen, but indicate appreciable amounts of available phosphorus. They are further characterized with high clay contents (> 60%), prominent slickensides, clay skins, absence of gilgai [30,31] and with smectite, corrensite, attapulgite and iron-rich clay minerals. They are moderately well drained. It is probable that this suite of minerals form complexes with organic matter during biological activity and/or during organic matter decomposition.

Morphologically, they have strong features of mollic, nitic and even vertic features along the soil depth. The surface horizons normally have granular to crumb structure, whereas sub-surface zones show blocky or prismatic structure of different grades. The vertic features of the surface soils remain suppressed due to the granular and/or crumb structure. Such a situation complicates the grouping of these soils into any of the recognized reference soil groups of the world. Philosophically, one may look for the proper soil grouping based on dominant criteria for management. In this respect, the dominant attribute of importance relates to organic matter immobilization. For this reason, we propose a new reference soil group called Immobilisols, reflecting organic matter immobilization. The form together with state of organic matter in such soils plays a dominant role leading to immobilization. Even if the soil has adequate total nitrogen, its availability to plants appears to be restricted due to protected soil organic materials by clay minerals or even amorphous materials. This might explain significant crop response to applied nitrogen fertilizer, even though the total soil nitrogen is 0.4%.

If the soil contains more total nitrogen, the actual amount of nitrogen to be added to soil for N-enrichment for crop requirement is more than any recommended level. In one study, where the soil was derived from volcanic materials, out of 1300 mg kg⁻¹ total nitrogen (0.13% total N), only 4.10 mg kg⁻¹ was NH₄ N and 10.44 mg kg⁻¹ was NO₃ N. This means that the remaining 98.9% of the total N was in organic forms. However, it is not quantified as to what amount of the soil organic matter is decomposed and how much is really protected physically and chemically. Such protected organic materials can hardly be utilized by microorganisms involved in decay process of soil organic matter. Such basic restriction in soil organic matter decomposition results in immobilization. It is proposed that the existing climatic condition and agro-ecology play a role in developing such soils which are potentially very productive with

proper management. The proposed Immobilisol at the Unit level (Level 2) may be vertic, mollic, nitic and even haplic. Further sub-division would be based on local factors influencing directly the management options of such soils. Ethiopia has, by and large, appreciable area covered with Immobilisols particularly on highlands [29]. In perception of climate change mitigation through carbon sequestration, a detailed systematic investigation would certainly disclose new horizon in days to come.

First vs Second Green Revolution

The first green revolution was solely credited to crop breeders to evolve high yielding dwarf varieties of certain cereal crops. This was a very crucial situation of food crisis across the globe. The release of such high yielding cereal varieties was accepted like a gift of God everywhere to combat against hunger. With great enthusiasm, government of the countries started supporting the farmers with inputs necessary for the recommended packages of crops such as tillage, irrigation, fertilizers and crop protection measures including insecticides, pesticides etc which all have been applied mostly through soils. The partial factor productivity of a soil then started going down besides high rate of nutrient mining, emergence of pollution and toxicity of heavy metals like arsenic, fluoride, chromium, lead and many others. With the increasing population, the land area is virtually decreasing and as such, the problem of food security is at critical stage, if not disastrous. More importantly, there is global need of food safety with balanced nutrition. However, with the advancement of technology generated in different facets as well as management techniques identified, we are now in a position to look for a better congenial environment coherent to the proposed soil based second green revolution in India (Table 3) that will strongly assure of congenial climate in days to come. As such, the need of second green revolution must be based on soil in order to assure a productive, profitable and sustainable agriculture besides a continuous process to sequester soil carbon at least to minimize the disastrous consequences of climate change.

Conclusion

The past may entail the issues, while present will scrutinize the challenges and based on critically documented issues and challenges, our efforts should aim at recognizing the priorities for framing the action plan on integrated basis to look for a healthy future environment congenial to our survival and livelihood on sustainable foundation of the earth. In such endeavor, the pedologic interventions do deserve special attention in integrating all the components including GHGs. There is need to develop and formulate a "pedo-ecologic zone" as a representative to a particular climate of a region in terms of its characterization, management and possible mitigation options. However, efforts are equally vital towards natural components contributing to climate change by disturbing the earth's equilibrium by specialist persons.

As more and more evidence come to light, we can have more and more confidence that may help in getting nearer the truth. It is true, for example, that sun is the centre of the solar system, that earth is not flat and that atoms is not solid. Science does not know the answer of every question for simple reason that every question is hardly covered by the objectives of an experiment. Science, as a rule, evolves raising new questions and new techniques to develop so that new types of measurements can be made. The global climate change involves many components including GHGs and deserves attentions from multi-disciplines for integrated efforts of mitigation. Let's start enlisting the components (all natural and manmade), which are directly or indirectly involved, then broadly classify into man-made and natural components and finally develop a strategic planning for mitigation. By and large, the man-made components imposing challenges to our climate may be minimized even on site-specific basis, if efforts are made systematically. But, we have to be consciously vigilant towards components contributing naturally beyond our control in changing the global climate. The important point is that the more mature the science, the more confident we can be towards mitigation of overall global climate change. In such exercise, (i) the carbon sequestration in type specific soils deserves immediate attention in a planned manner through conservation agriculture. This must follow (ii) a legal ban against land shrinkage. Moreover, efforts must be initiated (iii) to maximize the use of solar energy as well as bio-fuel as the substitute for coal and petroleum. If climate is changing, land would automatically be changed besides manifestation of other changes.

A new soil group proposed as Immobisols in Ethiopia is a good example to understand the soil based hidden facts of carbon sequestration. However, by restoring the soil health through conservation agriculture (as innovated by imposing "Soil Carbon Trade") following a strict policy to minimize the extent of land shrinkage (both rural and urban), a strong strategic base could be developed on way to maximize carbon sequestration as well as capturing the increasing trend of atmospheric temperature to its desired limit. Besides, global necessity to insure clean energies generation by minimizing coal and fuel burning, petroleum consumption and irreversible uses through non-farming activities of lands is inevitable. By and large, the world has to be seriously aware of technological generation for utilizable transformation of solar energy in different fields of interest.

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