Mitigation of Climate Change through Approached Agriculture-Soil Carbon Sequestration (A Review)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

It is projected that by 2030, the global population will rise to 8.5 billion influencing various changes to the whole globe. Since 1750, the level of carbon dioxide (CO₂) has increased sharply and exceeds more than 31 percent as a result of land use change and intense farming activities that require unique and modern actions to manage its climate-related risks. The earth is getting warmer day by day due to land use transition, intensive agriculture; global carbon (C) emissions have drastically increases after industrial revolution. Soil C depletion is enhanced by soil mismanagement, soil degradation and aggravated by land exploitation. Sources of emissions from various anthropogenic activities; land use change, burning of natural biomass, natural conversion to agricultural habitats, and soil cultivation. The soil as a dynamic natural entity has the potential of storing most of the C from atmosphere that will cause substantial decrease in CO₂ content that is enhancing global climate change. Through agriculture, soils can reduce CO₂ emissions in the atmosphere and store C while having good effect on food security, water quality and climate prior to the introduction of best management and restorative land-use practices. Most of the reduced C in soil carbon (SC) pools can be recovered by embracing conservation tillage (no-till, reduced tillage) with cover cropping and incorporating crop residues as mulch, nutrient management through

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integrated nutrient management practices, manure and organic amendments, biochar and using other productive soil management strategies. These management systems lead to preservation of lands that are being or have been depleted, increase carbon production, enhance soil health and decrease the amount of atmospheric CO₂ leading to climate change mitigation.

Keywords: Atmosphere; climate change; soil carbon; carbon dioxide; best management practices; conservation tillage.

1. INTRODUCTION

It is projected that by 2030, the global population will rise to 8.5 billion. Since the time of industrial revolution, mankind has proceeded to establish a disparity in the natural equilibrium of our world. Because of the increasing human population, there is a need to generate greater resource to meet the people’s daily needs. This indicated a need for rising in development of food as well as, land use for increasing this food and developing residential and commercial property. In 1999 the CO₂ concentration in the atmosphere rose from 280 parts per million (ppmv) in 1750 to 367 ppmv and is now rising at 3.3 Pg C a year (1 Pg = petagram = a billion tonnes) [1]. Forest conversions through deforestation by means of complete burning to support this expansion; while the property was repurposed for human use e.g. the Amazon rainforest approximately contributes 2 billion tonnes of CO₂ per year [2] accounting 5 percent of global emission. A substantial drop in photosynthesis rate has been seen as one of the cause which decreases CO₂ amount taken from the atmosphere. This drastic factor change in the loss of natural ecosystems will be dramatic, and we may find ourselves struggling to adapt [3]. “Anthropogenic” behaviors interact with the carbon cycle on a regular basis because C is one of the most essential components that impact almost any climate. With geological records, the climate is continuously changing and its size causing climate change is a major concern around the world at this rapidly changing rate. There are no new phenomena in the world with regard to climate change [4, 5]. Climate change clearly represents the increase in temperature in the soil and atmosphere, changes in the precipitation, declining groundwater, floods caused by heavy rainfall, earthquakes and increasing sea levels due to the glacial melting. While in some situations this is a natural process, it is due to anthropogenic activities. The factors that lead to climate change are the result of various anthropogenic deforestation, land change, intensive farming and the decomposition of natural soil biology, erosion and natural fires, increased population causing rapid industrialization [6]. C plays a vital role in life on earth; plants absorb C in the form of CO₂ through photosynthesis from the atmosphere and utilize it as energy source. C occurs in four wide pools: lithosphere, ocean, soil and atmosphere. The earth’s soil functions as a sink and fluxes in the soil-plant-atmosphere cycle are essential in the terrestrial world. Most C occurs in organic form in the terrestrial environment. Both key parts of the general C pools can be split into active and passive C pools. Four large SOM pools, such as plant residues, organic particulates, humus C and recalcitrant OC, are also evident. Soils usually contain a 3-fold amount of C or 4-fold more than in living substances. Soils have an immense storage potential and so a small percentage increase in soil C storage can have a significant effect on climate. Soil management practices influence change in soil C efflux. Agricultural soils may be used as a C sink than a source by various management strategies and models of land use. The principle practices capable of increasing SOM are; land restoration through afforestation / reforestation, conservation of natural ecosystems, covering bare soil (cover cropping), and adding organic matter in the form of organic fertilizers, planting nitrogen fixing plants, biochar and residue incorporation. For higher yields, integrated nutrient management and conservation tillage (no-till, reduced tillage) systems increase soil C. Afforestation and reforestation systems on long term basis sequester more C. Soil C conservation, management, and storage have wide potential to combat climate changes and food insecurity. Soil C is considered the environmental management system key for sustainable soil health as well as agricultural productivity.

2. CLIMATE CHANGE AND CARBON SEQUESTRATION

The climate is continuously changing when seen with geological records. This rapid rate at which this change is coming up and its magnitude are of great concern worldwide. In terms of climate change India ranks as the 5th most vulnerable
country to be affected due to enhancing attributes by the drastic factor [7]. In India, a one-metre sea-level rise is estimated to displace nearly 7.1 million people; about 5764 sq. km of the land area will be lost 4200 km of roads as well. That is because various factors, such as: “anthropogenic deforestation, land-use change, intensive farming practices” and “natural soil organic matter decomposition, erosion, natural fires” are leading to climate change. Climate change has a very strong link with greenhouse gases of which a major contributor is CO$_2$. This gas being symmetrically aligned has the tendency to absorb long heat wave radiations from the sun. A new approach of C sequestration; a term used to denote natural as well as intentional emissions measured in Gt. CO$_2$ emissions in the natural system before mankind contributed to natural cycles that make up the global "carbon cycle" which held equilibrium between capturing CO$_2$ and returning it back into the atmosphere. The established processes of CO$_2$ acquisition are called C sinks. China along with India being the two large-scale nations having vast human race will continue to be sources of global C emissions. Thus efforts to minimize CO$_2$ emissions must be made [8]. The projected mean C level in the twenty-first century would exceed 600Pg with centuries to millennia of residence if the only central focus of the “C-neutral” solution is to be sequestration rather than to eliminate emissions [9]. However, even a small 2–3 Pg C Year sequestered from one of the pools, would adversely affect long-term planning for centuries. The dynamic nature, social, and environmental conditions of climate change contribute to a variety of health risks. There are various risks and pathways that are classified in three ways (Table 1) [10]. Worldwide research experts are focused on the assessment of global C fluxes, possible capacities, drawbacks of different methods for sequestration C and mitigation of the effects of climate change. Elucidate the process of sequestration and mineralization of SOC in aggregates is important to reducing climate change and decreasing soil depletion risks.

### 2.1 Impacts of Climate Change

- The Polar caps around the world are melting. That comprises glaciers, West Antarctica, the Arctic Sea and Greenland ice sheets.
- Ice melting contributes significantly to an increase in the level of sea. The sea level (global) keeps growing at 3.2 mm a year, and is increasing rapidly in recent years.
- Increasing temperatures are affecting wildlife. 90 percent of the Adelie penguin specie in the western peninsula has been subjected to extinction due to vanishing ice in the Antarctica.
- Temperature changing patterns has caused certain species of butterflies, foxes, and mountain plants to migrate to cooler areas.
- On average, precipitation has increased worldwide (rain and snowfall). However, some regions face more severe droughts, risks of wild fires, loss of crops and water shortages increase.

### Table 1. Categories of Climate Change Risks to Health due to Causal Pathway (McMichael et al., 2013)

| Risk category | Causal pathway |
|---------------|----------------|
| Primary       | Direct biological consequences of heat waves, extreme weather events, and temperature-enhanced levels of urban air pollutants |
| Secondary     | Risks mediated by changes in biophysically and ecologically based processes and systems, particularly food yields, water flows, infectious-disease vectors, and (zoonotic diseases) intermediate-host ecology |
| Tertiary      | More diffuse effects (e.g. mental health problems in failing farm communities, displaced groups, disadvantaged indigenous and minority ethnic groups) Consequences of tension and conflict owing to climate change related declines in basic resources (water, food, timber, living space) |

### 3. CLIMATE CHANGE AND AGRICULTURE

At an increasing trend, the earth’s climate continues to warm up due to increasing temperature rate and the effect of this is considerably a major challenge to mankind especially for farmers and farming communities around the world. Climate and its variable influence in many ways on all economic sectors, such as rainfall variations contribute to flooding intensity and frequency. Any rise in
temperature may significate a spike mean level of seas, impacting vast populations, e.g. peninsular and coastal regions. It can increase precipitation by 15 to 40 percent and cause a 3-6 degrees Celsius annual average temperature increase. The rapid changing climate directly impacts by agriculture throughout the world mainly in terms of food security i.e. food availability, food accessibility, food utilization, and food system stability; which will influence health, living resources and food production and distribution of the human race [11].

3.1 Influence of Climate Change on Agriculture

1. Floods- The increase in sea levels increases flood frequency and intensity in farms in coastal regions. These expensive damages of floods devastate livestock and crops, speed up soil erosion, water pollution and other conducing factors.

2. Droughts- Inadequate water supply may be equally damaging. In many parts of the world, severe droughts have affected animal life, plant-crops and farmers. Through increased temperatures exacerbation of droughts would arise.

3. Changes in crop and livestock viability- Selection of crop varieties and animal breeds by farmers that suit favorable conditions. As conditions are changing rapidly, many farming communities are being forced to adapt to new investments in capital, new markets and new practices.

4. New pests, pathogens, and weed problems- New threats are going to arise as farmers are trying new crops, animals, and practices mechanisms.

5. Degraded soils- The soil has been subjected to various alterations that have caused a decline in soil health; Changes as fertility, reduced water-holding capacity, and increased vulnerability to erosion and water pollution that substantially leads to reduced production levels.

6. Simplified landscapes- Farms are treated as a crop rather than a managed ecosystem through industrial agriculture, having minimum biodiversity. This lack of diversity in farms leads to increased risks.

7. Intensive inputs- Through heavy reliance and use of synthetic pesticides, weedicides and fertilizers the initial cost increases that is a burden to the farming community.

4. GLOBAL WARMING

Over the course of this century, global warming has caused the occurrence of increased global air temperatures near the Earth’s surface. Since the middle of the 20th century, climate scientists have collected detailed observations concerning diverse weather patterns, temperatures, precipitation, storm and related climatic influences, ocean current and the chemical composition of the atmosphere. This indicates that earth’s climate has changed throughout ever since the beginning of geology and human activities and these activities have been a significant contributor to climate change since time of Industrial Revolution. During timeframe of 1880 to 2012, the IPCC recorded a global mean temperature increase of about 0.9 degrees Celsius. The rise is nearer to 1.1 degrees Celsius when measured by mean temperature since 1750 to 1800’s. This estimate has also been endorsed in IPCC report 2018 which states, since pre-industrial times, human and its behavior are responsible for average rise in global warming temperature to 1.2 degrees Celsius and that the greater part of warming could be due to human activities in the 20th century [12]. Many climatologists agree that major social, economic and ecological loss will result if world average temperature increases by just 2 degrees Celsius. The extinction would grow, with changes in farm patterns and the increase in maritime levels of many animal and plant species. The above scenarios depend mainly on the concentration of some trace gases, referred to as greenhouse gases which, by burning fossil fuels for industry, transports, and home uses, have been injected into the lower atmosphere. The so-called greenhouse effect rises causing earth’s surface heating up and the lower atmosphere is influenced by water vapors, CO₂, methane, nitrous oxides as well as other pollution from greenhouse gases. The IPCC stated in 2014 that the atmospheric concentrations of C, methane and nitrous oxide are above those in the 800,000 year ice core. Of all these gases, CO₂ is of the greatest importance both because of its greenhouse effect role and because of its role in the human economy. At the start of the industrial era of mid-18th century, atmospheric CO₂ levels were higher at about 280 ppm. Until mid-2018, fossil fuels had risen to 406 ppm, and the existing fuel consumption is projected to grow to 550 ppm by the middle of the 21st Century. The principle, CO₂ concentrations will be doubling in 300 years. The magnitude, intensity, and impacts of rising surface temperatures on human lives and need
for actions to minimize and cope with future warming are still being studied by researchers worldwide. The amount of atmospheric CO$_2$ has increased from 280 ppm to 395 ppm and CH$_4$ from 715 ppb to 1882 ppb and N$_2$O from 227 ppb to 323 ppb from 1750 to 2012. The Global Warming Potential (GWP) of gases, i.e. CO$_2$, CH$_4$ and N$_2$O, amounts to 1, 25 and 310 respectively (Fig. 1) [13].

Global warming scenarios are projected to indicate an increase by 1.4 to 5.8 degrees Celsius by 2100 of the global average surface temperature. The forecast warming rate in the last 10,000 years is unprecedented

4.1 Effects of Global Warming

Global warming indications are much more complex than rising temperatures around the world. The earth is warming from Northern to the Southern Pole. Since 1906, average global surface temperature in sensitive polar region substantially increased over 0.9 degrees Celsius. The impacts of rising temperatures do not look for a far-reaching future global warming is now having repercussions. The heat melts glaciers and sea ice, changes the pattern of precipitation, and moves animals. Most people see global warming as synonymous with climate change; however scientists tend to use “climate change” to describe the complicated changes that are adversely affecting our planet's climate. Average temperatures not only increase but also extreme weather, changes in population and habitat of wildlife, the rising seas and a number of other impacts are included as part of climate change. These changes are regulated by addition of greenhouse gases in the atmosphere as a result of mankind.

![Temperature Increases for Various Emission Scenarios](image)

Fig. 1. Global Scenario of Climate Change (Source: Anupama adapted, 2014)
5. GREENHOUSE EFFECT

Warming of earth’s surface and troposphere is attributed by high temperature elevations that are a result of various greenhouse gases which are water vapour, CO₂, methane and other gases in the air is known as Greenhouse effect. The greatest effect among these gases is due to water vapour. Greenhouse gas levels constantly are increasing mainly CO₂ and methane at a 0.4 percent Year (Table 2) since 1750 [14]. The French mathematician Joseph Fourier is sometimes regarded as the 1st individual who coined the term “greenhouse effect” in 1824. Svante Arrhenius a Swedish physicist and physical chemist are marked as the person who made it clear as how heat is captures in the atmosphere. The mechanism through which this process takes place is when the surface of the Earth is heated by sunlight, radiation in the form of energy is sent back to space as infrared waves. Unlike visible light, this radiation is absorbed by the atmospheric greenhouse gases thus causes temperature increment (Fig. 2) [15]. In exchange, the warm atmosphere radiates infrared radiation out towards the surface of Earth. The Earth average surface temperature would be near to −18 degrees Celsius in the absence of heat due to greenhouse effect. Since greenhouse effect being natural phenomena possibilities of this effect could exacerbate the greenhouses gases to the atmosphere due to human activities. Atmospheric CO₂ concentrations have risen by nearly 30 percent, while methane levels have doubled by the end of the 20th century since the industrial revolution. By the end of the 21st century, man-kind could cause a global temperatures increase by 3-4 degrees Celsius. As a result of substantial increment at the following rate this would negatively affect the earth’s climate causing extreme conditions such as drought and reduced food production affecting human lives.

Table 2. Modification of atmospheric trace gas levels since 1750 (IPCC modified 2001), the industrial revolution

| Gas                        | Present concentration | Percent increase since 1750 | Present rate of increase (%/year) |
|----------------------------|-----------------------|-----------------------------|----------------------------------|
| Carbon dioxide (CO₂)       | 379 ppm               | 31                          | 0.4                              |
| Methane (CH₄)              | 1745 ppb              | 151                         | 0.4                              |
| Nitrous oxide (N₂O)        | 314 ppb               | 17                          | 0.25                             |
| Chlorofluorocarbons (CFCs) | 268 ppt               | a                           | decreasing                       |

Note: parts per million (ppm), parts per billion (ppb), parts per trillion (ppt).

![Fig. 2. Greenhouse effect on Earth (Source: Encyclopedia Britannica, Inc.2012)](image-url)
5.1 Causes of Global Warming

5.1.1 The greenhouse effect

The average earth surface temperature is determined by a combination of various solar and land radiation types. Solar radiation is generally called shortwave radiation, since it is relatively large and has relatively short wavelengths and is a visible component. Terrestrial radiation, however, is often referred to as "long-wave" radiation because of its relative low frequency and its relative range, and can be found. According to solar constant, 1366 watts of solar radiation annually per square metre in which only half of the surface of the planet receives solar radiation at all times which implies that the earth's surface only absorbs a small portion of the radiation. Earth's surface temperature is linked to the magnitude through “Stefan-Boltzmann law” of outgoing radiation emissions. This law describes the power radiated from a black body in terms of its temperature. It states that the total energy radiated per unit surface area of a black body across all wavelengths per unit time $j$ is directly proportional to the fourth power of the black body's thermodynamic temperature $T$: $j = \sigma T^4$. This absorption means that some fractions do not escape to space directly. As the same amount of radiation emitted by greenhouse gases, these radiations are absorbed in all directions equally. Atmospheric greenhouse gases contribute to warming of surface and below surface atmosphere. It is a must to know the difference between the “natural” greenhouse effect and the “enhanced” greenhouse effect which is linked to humans. The natural greenhouse effect is related to Earth's natural components, particularly water vapour, CO$_2$ and CH$_4$ as a surface warming characteristic. The average Earth’s temperature in its absence would be about 33 degrees Celsius. In particular, burning of fossil fuels results in increased levels of the major greenhouse gases which could make the atmosphere warmer by several degrees. In 2014, India's GHG profile represented 68.7 percent of overall energy emissions which was dominated by energy sector emissions, according to the World Resources Institute Climate Analysis Indicators Tool. In the power sector 49 percent of energy and heat generation emissions were produced, followed by 24 percent from manufacturing and construction. Agriculture being the second largest source contributing 19.6 percent of overall emissions accounting with 45 percent of agricultural emissions coming from enteric fermentation. Industrial processes, forestry, land utilization and waste accounted for 6 percent of total emissions respectively, 3.8 and 1.9 percent [16, 17] in 2014 (Fig. 3).

![Fig. 3. GHG Emissions by Sector, 2014 (Source: WRI CAIT 4.0. 2017, FOASTAT, 2018)](image-url)
Radiative forcing, as described by IPCC, determines how much radiation energy is affected by any climate factor on the surface of earth and the lower atmosphere temperature. Climate factors are grouped among those that are a result of human activity and those occurring due to natural forces (sunlight), which are calculated for the period 1750 to the current day for each factor called forcing values. Climatic factors contributing to warming the surface of the planet is known as 'Positive forcing', whereas 'negative forcing' involves factors cooling the surface of the planet. Average solar radiation of about 342 watts strikes the earth's surface every square meter per year, which in turn can be associated with an increase or fall in earth's surface temperature. Surface temperatures can also increase or drop as the distribution of terrestrial radiation shifts in the atmosphere. In some situations, forced radiation has a natural origin, for example during destructive volcanoes, in which ventilated gas and ash blocks some of the surface solar radiation. In other cases, the radiative forcing comes from anthropogenic sources (Fig. 4) [18]. Combining positive and negative values of radiative forcing with all interactions, between factors of climate accounting net total increase in surface radiation as result of human activities) since beginning of Industrial Revolution.

5.1.3 Influence of human activity on climate

Over the centuries the earth's surface has changed significantly through human actions e.g., intensive agriculture, construction, and pasture [19, 20]. Almost all of the land with population growth is being used [21]. Human activity has changed the Earth’s radiative balance at different timescales and spatial scales, affecting the global surface temperature. A higher level of greenhouse gas concentrations in the atmosphere is the biggest and most known anthropogenic effect. Humans readily influence the climate by changing aerosol and ozone concentrations and by changing the earth's surface terrestrial area.

6. GREENHOUSE GASES

Greenhouse gases warm the surface of the Earth by increasing the radiation from the net downwards to the surface. The relation between atmospheric greenhouse gas concentration and the associated positive long-wave surface radiation forcing varies by gas. The great extent of complexity for each greenhouse gases chemical property and the relative amount of long-wave radiation each can absorb is intrinsic.

- Water vapour- Water vapour (H₂O) being a greenhouse gas has the most potent in the atmosphere (earth) but is different from the
remaining gases found in the atmosphere. It is not considered a direct agent of the radiative forces, but is contained in the climate system. It is not simply possible to change the amount of water vapor present in the atmosphere directly by human activity but instead is regulated by air temperature. The warmer the surface, the greater the rate of evaporation of the soil. Due to increased evaporation, more water vapor can be absorbed by long-wave radiation and emitted downstream in the lower atmosphere.

- **Carbon dioxide** - CO₂ is the most important greenhouse gas. Sources of atmospheric CO₂ comprise; eruption of volcanoes, burning, decomposition of organic matter and through respiration by living entities. The sources of CO₂ on an average basis through physical, chemical, biological processes are balanced where CO₂ flux is removed from the atmosphere. There are several natural “sinks” of CO₂ like vegetation including crops, plants and trees that absorb this gas through photosynthesis. The average rate of CO₂ accumulated in the atmosphere between 1959 and 2006 was 1.4 ppm a year and from 2006 to 2018 was approximately 2.0 ppm per year. All in all, this accumulation rate was consistent. The annual total CO₂ emission (2018) is approximately 36.58 billion t excluding emissions from land use change (Fig. 5) [22].

- **Methane** - Methane (CH₄) is the second biggest greenhouse gas. The radiative forcing generated by the molecule is higher, and the CH₄ is more effective than CO₂. The infrared window is less saturated in the spectrum of the wavelengths of radiation absorbed by CH₄, to add more molecules in the region. CH₄ is, however, much lower than CO₂ and its concentrations are generally measured per ppb rather than ppm in the atmosphere by volume. It has significantly lower atmospheric residence time than CO₂; time for CH₄ is approximately ten years compared to CO₂ having hundreds of years as residence time. Tropical and northern wetlands, methanol oxidizing bacteria feeding on organic materials, volcanic and methanic hydrates trapped in ocean-rich regions and polar permafrost are natural sources of methane. Atmosphere is the natural sink for CH₄ as it reacts rapidly with hydroxyl radicles in the troposphere that forms CO₂ and H₂O as water vapor. CH₄ is destroyed when it arrives at the stratosphere. Another natural sink is soil, in which bacteria oxidize methane.

- **Ozone and other compounds** - Surface ozone (O₃) is the next most important greenhouse gas. O₃ is a serious environmental problem; the stratosphere O₃, which plays a very specific dynamic in planetary balance of radiation, should be distinguished from the natural one. Surface O₃'s primary natural source is the deviation from high atmosphere of stratospheric O₃. In comparison, photochemical reactions involving atmospheric carbon monoxide (CO) pollutant are the primary anthropogenic source for surface O₃. The natural concentration of O₃ on surface is estimated at 10 ppb having a net radiant force at about 0.35 watts per square meter due to anthropogenic emissions.

- **Nitrous oxides and fluorinated gases** - Other trace gases of the industry which have greenhouse characteristics include nitrous oxide (N₂O) and fluorinated gases (halocarbons), sulphide hexafluorides and perfluorocarbons (PFCs). Nitrous oxide is responsible for radiative forcing of 0.16 watt per square metre, and fluorinated gases for 0.34 watt per square metre are jointly responsible. Because of natural organic soil and water reactions, nitrous oxides have small background concentrations, while fluorinated natural gases almost completely owe their existence to industrial sources.

7. **CARBON AND SOIL CARBON POOLS**

C plays an important role in life on earth; plants consume C from the environment (atmosphere) in the form of CO₂ through photosynthesis and used as a source of energy. When a plant dies; the foliage, stems fall to the earth as organic matter and are then decomposed into the soil by microorganisms that recycle this carbon back to the atmosphere. Organic matter (OM) remains persistent to no decomposition, becomes biologically or chemically attached to the soil making up the carbon reservoir of the earth known as the soil carbon pool. C is present in four large pools: Lithosphere (earth’s crust), ocean, atmosphere and terrestrial ecosystems (Fig. 6).
The soil has a crucial role in the terrestrial environment as sink and fluxes within the soil-plant-atmosphere cycle. C is present in trees, plants, animals, soils and microorganisms. Out of these the plant and soil system having largest fractions of carbon. Most of the carbon in terrestrial ecosystem exists in organic forms. The overall C level present in world soil is estimated at 1500 Pg C. Prevalent soil C is organic carbon (OC) from dead plant materials and microorganisms. The abundance of OC decreases with soil depth and a dominant 1 meter deep carbon fraction in soils is sequestered, although this may depend on soil types and the environment. Majority of C in soils enters in form of dead plant remains which is decomposed by soil microorganisms mainly bacteria and fungi. Through this decomposition means carbon is released by metabolism (respiration) by microorganisms. Soil has a potential of holding approximately 2,500 giga ton (Gt) of carbon [23]; global soil C pool stores more than three times that of the atmospheric carbon pool [24]. SOM is regarded as the organic fraction of soil composed by plants and animals in distinct decomposition phases, microbial cells.
and tissues [25]. Due to its function in the various physicochemical properties of soil such as soil structure, capacity for water retention, soil biodiversity, soil fertility, nutrient availability and aeration, water erosion resistance, SOM is considered an important primary soil health indicator [26] allowing ecosystem growth and sustainability. The Four main SOM pools are plant residues, particulate OC, humus and recalcitrant OC which differ in chemical composition, stage of decomposition and role in soil functioning and health. The two fractions of Soil C pools are SOC and soil inorganic carbon (SIC) respectively. In dry areas, the SIC pool is particularly important. The concentration of SOC ranges in arid areas from low in temperate to high in organic or peat soils (Table 3) [27]. In addition to influencing total organic carbon stocks (TOC), management affects the composition of C in these pools. Understanding how C pools change in management responses will provide useful information about the likely functioning of the soil and health. At a different rate and time period each C pool decomposes or transforms over involving various soil processes.

![Fig. 6. Global C pool](image)

### Table 3. World soils C pool (Eswaran et al. adapted, 2000)

| Soil order   | Area (Mha) | Soil organic carbon | Soil inorganic carbon |
|--------------|------------|----------------------|-----------------------|
|              |            | Density (tons/ha)    | Pool (billion tons)   | Density (tons/ha) | Pool (billion tons) |
| Alfisols     | 1262       | 125                  | 158                   | 34               | 43               |
| Andisols     | 91         | 220                  | 20                    | 0                | 0                |
| Aridisols    | 1570       | 38                   | 59                    | 290              | 456              |
| Entisols     | 2114       | 42                   | 90                    | 124              | 263              |
| Gelisols     | 1126       | 281                  | 316                   | 6                | 7                |
| Histosols    | 153        | 1170                 | 179                   | 0                | 0                |
| Inceptisols  | 1286       | 148                  | 190                   | 26               | 34               |
| Mollisols    | 901        | 134                  | 121                   | 96               | 116              |
| Oxisols      | 981        | 128                  | 126                   | 0                | 0                |
| Rocky land   | 1308       | 17                   | 22                    | 0                | 0                |
| Shifting sand| 532        | 4                    | 2                     | 9                | 5                |
| Spodosols    | 335        | 191                  | 64                    | 0                | 0                |
| Ultisols     | 1105       | 124                  | 137                   | 0                | 0                |
| Vertisols    | 316        | 133                  | 42                    | 50               | 21               |
| Total        | 13083      |                      | 1526                  |                  | 945              |
The two major fractions of the general carbon pools can be divided into active and the passive soil carbon pools. The active pool (also called labile carbon) is composed primarily of living organisms, crop residues and manures having turnover rates from seasons to years. This pool plays a vital role in structural stability and as a supply of nutrition for soil microorganisms, as it mainly consists of « fresh » materials. Active soil level C changes quickly with tillage and cultivation practices. The passive pool has turnover period of hundreds to thousands of years. Being very stable and physically protected from the activity of soil microbes because it is compelled with organic-clay complexes. This pool contributes to cation exchange capacity (CEC), and water-holding capacity. It is very slow to change and primarily lost through wind and water erosion of topsoil (Fig. 7).

Humus is part of passive pool, which promotes root development and plant growth [28]. The SOC pool is a dynamic C cycle aspect closely connected with the atmospheric C pool.

### 7.1 Soil Carbon Sequestration

Terrestrial sequestration also known as "biological sequestration" is usually achieved by soil management activities that increase C absorption like; regeneration, afforestation and grasslands or minimize CO₂ emissions by reducing intensive tillage operations, land use change. "Carbon farming" commonly known as soil C sequestration (regenerative farming) involves a number of ways to manage land use types, particularly agriculture, so that soils can absorb and retain more C. Intensive agricultural practices and land use change has caused a decrease in global soil C by approximately 800-850 billion metric tons of CO₂ (GtCO₂). Soils being the heart "sensitive region- organ" of Earth, the small outermost portion on which humans depend mostly in day to day need [29, 30]. Soils contain 3 times volume of carbon currently in atmosphere or 4 times more as found in living matter. Soils have a tremendous storage capacity thus enhancing soil carbon storage by few percentage can make a considerable impact. Increase in soil carbon and simultaneously flux of CO₂ in the atmosphere can be reduced and fixed to the soil in various ways that involves sustainable agricultural strategies like; conservation agriculture, decreasing soil disruption, low-till or no-till or reduced till approaches; carrying out planting programs, increasing land surface cover, cover cropping following crop rotations, including planting crops or double crops instead of leaving fallow fields, incorporating crop residues, mulching and adding organic manures to fields. These activities, in addition to bringing local economic and environmental benefits, will absorb CO₂ from the atmosphere and store it in soils, rendering it a method of C removal.

### 7.2 Agricultural Management Strategies to Sequester Carbon in Soils

Some of the best management practices that can enable CO₂ sequestration are as below:

#### 7.2.1 Tillage

The primary objective of tillage is physical destruction top soil layer for seed bed
preparation, introduction of fertilizers and likewise weeds management. Various soil types, temperature, rainfall, management and technology in different regions lead different tillage operations. For sequestration of C in agricultural soils, interaction between tillage, SOM dynamics and composition of soil is necessary. Tillage practices like conventional tillage (CT) causes reduction in soil carbon accounting 35-60 percent and as low as 15 percent globally. Due to intensive tillage operations SOC oxidation occurs that causes emission of CO\(_2\) into the atmosphere. Among the best tillage practices the 2 known tillage practices that causes positive impacts on soil carbon sequestration are; no-till, and reduced till and conventional tillage systems. No tillage increases soil quality and aggregation amounts, while conventional tillage acts against the structure of soil, which enhances the decomposition of the SOM. Conservation tillage practices hold more crop and crop residue on the soil surface and thus providing a higher SOC concentration at surface layer as compared to conventional tillage. Both tillage operations with cropping systems cause fluctuations in behavior and activities of microbial that eventually affect dynamics and stability of SOC. Also by decreasing soil tillage and increasing crop strength, soil mineralization may be minimized. Decrease in soil temperature by using surface mulches and no-till strategy is necessary to maintain soil organic matter stocks mainly in the tropical soils. Higher biota and especially microorganism density usually occur in no-tilled soils. Most of the studies indicate that no-till can quickly increase soil C, especially on the earth's surface, in conjunction with improvements in aggregation. In order to stabilize atmospheric C, the introduction of conservation tillage is expected to sequester 25 Gt C globally for the coming 50 years.

7.2.2 Cover crop

Cover cropping is mainly done for soil advantages rather than crop production. Cover cropping improves soil quality by increasing SOC biomass, improving soil aggregations and fertility and retaining soil against water erosion. C sequestered through cover cropping is subjected to different types of soil, management, elevations and the climate [31]. Past studies evaluate the amount of 0.22 tonnes per acre per year for cover crops emitting carbon in soil [32]. In-situ application of green manures increases biomass added to the soil, which allows increased C sink in the soil to be established. The benefits of introducing conservative tillage for SOC sequestration are greatly enhanced with growing cover crops during the rotation cycle. Increase growth of leguminous cover crops increase biodiversity, residue feed efficiency and SOC pooling [33, 34, and 35]. Ecosystems having large biodiversity are known to consume and sequestrate more C than those with reduced or decreasing biodiversity. Drinkwater et al. [36] has reported that legume based cropping systems decrease soil C losses and nitrogen. Sainju et al. [37] observed that adoption of no till with hairy vetch will increase SOC. Also Franzluebbers et al. [38] found that forage management increases the SOC stream. Berzseny and GYearffy [39] documented the beneficial impact of increasing cover crops on enhancing SOC pool in Hungary. Adoption of cover cropping systems with intensive row cropping rotations with varying tillage treatments can mitigate climate change and sequester more SOC.

7.2.3 Crop rotations

Crop rotation implies series of crops cultivated on the same region of land in frequently repeated successions. Successive crops can last two or more years. The sequestration of C is influenced to a great deal by crop rotations, climate, soil and multiple crop management activities. Various legume crops, like lentils, peas, sesbania, alfalfa, chickpea and other known may serve as C and N sources. Implementation of crop rotations, in particular by leguminous cover crops containing C compounds are considered more resilient to microbial metabolism, will render soil C stable. The annual cropping rotations sequestered 27–430 kg C·ha\(^{-1}\) Year as compared over bare fallow crop rotations [40]. SOC sequestration is more likely in sub-humid than in drier conditions with crop rotations without bare fallow. Various types of cropping systems can indeed be helpful in carbon sequestration, namely the, ratoon cropping, cover cropping, and companion cropping system. Intercropping that involves intercropping of rows, mixed cropping, and intercropping of relays may raise revenue, and can improve soil quality. Nayak et al. [41] stated that the rotating rice-wheat system in the Indo-Gangetic Plains is the most effective cultivation system. A few of the intercropping examples include cotton and peanut, wheat and mustard, wheat and chickpea, peanut and sunflower. Thus long term organic agriculture can indeed increase organic carbon in soil compared with conventional agriculture [42]. Taking into account
economic factors, choosing optimal rotation of cropping systems accordingly with soil-environmental factors may be helpful in C sequestration that not only increases plant productivity, fertility of soils but often lowers CO₂ emissions into the atmosphere.

7.2.4 Nutrient management

The sequestration of C in soil requires integrated nutrient management (INM). The lack of N, P, S and other building blocks of humus would severely limit the process for humification [43]. The effectiveness of sequestration is lowered when C and N are not managed properly [44]. The SOC sequestration level is also strengthened with an increase in biomass C application [45]. Chemical fertilizers, particularly N₂O, are a source of GHG emissions. In addition to this, the manufacturing of fertilizer and its transport are both correlated with GHG pollution. Through application doses of 50 percent NPK + 50 percent N through FYM in rice and 100 percent NPK in wheat consequently sequestered 0.39, 0.50, 0.51 and 0.62 Mg C ha⁻¹ Year. Adopting rice-rice system (RRS) under reduced tillage (RT) or no-till (NT) with INM is recommended for enhancing the productivity, C and N sequestration in paddy soils [46]. Liebig et al. [47] and Dumanski et al. [48] found that, relative to unfertilized samples, high N dose treatments improved SOC sequestration concentrations. Ridley et al. [49] revealed that through the input of P and lime SOC pool increased in the 0–10 cm layer over 68-year (0.17 Mg C ha⁻¹ Year). Effective usage of soil-based fertilizers can be helpful in optimizing carbon sequestration alongside full crop output and in reducing emissions of various GHGs.

7.2.5 Organic manures and amendments

Another significant SOC sequestration technique is the use of manures and other organic amendments. Long-term studies in Europe revealed that with application of organic manures the intensity of SOC sequestration is larger than chemical fertilizers [50]. The rise of 10 percent over 100 years in Denmark [51], 22 percent over 90 years in Germany [52], 100 percent over 144 years in Rothamsted, UK [53] and 44 percent over 31 years in Sweden [54] in the SOC reservoir through long-term manuring at 0–30 cm depth. Manure application is essential for conserving soil health and it is a basis of C even its usage in various crop fields has an impact on C content. Use of organic amendments as substitution and additional nutrients has a beneficial impact on soil C sequestration and is often used as a C sink. In soils that have paddy cultivation, high clay content has ability to sequester more C [55]. Maltas et al. [56] reported that organic amendments viz. green manure, cereal straw, fresh cattle manure in 2 doses 35 and 70 t ha⁻¹ and cattle slurry has the potential to supply 25-80 percent more C input to the soil. Uhlen [57] and Uhlen & Tveitnes [35] stated that manure applications could increase the sequestration of SOC at a pace of 70–227 Kg ha⁻¹ Year over 37–74 years. In contrasted to just NPK application, FYM along with NPK applications improves C sequestration in rice-wheat cropping method, whereas in green manuring, relative to applying FYM along with green manure, sequestered more C in Maize-Wheat crop rotation. In addition to increasing net primary production, composting also enhances the soil C quality. This all means that, along with other inorganic fertilizers, the usage of livestock waste, compost is advantageous for both plant health and climate.

7.2.6 Biochar

Biochar development is based on a process initiated thousands of years ago in the Amazon Basin, where the indigenous people produced islands of thick, fertile soils called terra preta ("dark earth"). Anthropologists assume that the intended placement of coal in soil through cooking fires and middles led to a high productivity and C content in soils, sometimes with pieces of broken soil pottery. Biochar is enhancing soils by transforming crop waste into a fertile soil enhancer that preserves carbon and fertilizes fields. It is widely regarded as an effective means of C sequestering. It can successfully be used in concrete constructions as a C sequestering admixture to also help waste recycling [58]. Production of biochar in association with soil preservation has been proposed as one potential way of decreasing CO₂ amount in the atmosphere [59]. Biochar climate change-mitigation ability derives mainly from its extremely recalcitrant nature that delays the process of return to the atmosphere of photosynthetically-fixed C [60]. Several studies have shown that Biochar use decreases polysaccharide / C co-location by decreasing C metabolism due to C fixation in organic soils. Combining Biochar with manure can decrease CO₂ and N₂O as comparing to manure sandy loam soil but not from the clay loam soil. However, higher amounts of application of
biochar (> 10 Mg ha\(^{-1}\)) and long-term monitoring are needed to assess the impact of biochar on GHG emissions from the soil surface. Transformation of all sustainably produced crops to increase bioenergy, rather than biochar, output will even mitigate up to 10 percent of global anthropogenic CO\(_2\)-Ce emissions. Biochar and bioenergy’s relative climate-mitigation capacity depends on productivity changed soil and fuel intensity C being compensated with forms of biomass [61]. Under all other cases, the biochar’s climate-mitigation capacity is greater.

7.2.7 Microbial biomass management

The activities taken by soil microbes can be beneficial in sequestration of biological C because microbes enhance physical, chemical and biological properties of the soil. Soil biota is made up of a significant number and a variety of micro- and macro-organisms, and is the living component of soil. Their main role is decomposition of organic matter and modifications of organically bound N and minerals available to plants. Micro and macroorganisms includes bacteria, algae, fungi, protozoa, and certain nematodes. Residues of microbial biomass (i.e., necromass) have been viewed as an important source of SOM. Microbial cell envelope fragments therefore contribute a lot to the formation of SOM [62]. It has been shown that species-rich plant communities are more productive and show increased storage of SOC in the over the long term. Soil microorganisms are essential to transforming organic plant matter into SOC. Plant species richness (PSR) boosts the growth and turnover of microbials and increases microbial biomass and necromass. PSR enhances respiration by microbes, but the effect is less strong than for microbial growth. As compared, PSR does not affect respiration specific to microbial carbon use efficiency (CUE) or biomass [63]; also PSR enhances SOC content through its major contribution on the carbon content of microbial biomass. In the design model, soil mineralization of organic N is carried out at a microscale by soil microbes [64]. Song et al. [65] found C sequestration is exhibited by the bacterial order Rhizobiales, the fungal order Russulales, and δ15N. Hence the use of various species of microorganisms, which are good for soil and climate, can increase sequestration of soil C, boost crop growth and yield.

8. CONCLUSION

The industrial revolution has caused the climate to change at a faster rate due to the fluxes of GHGs in the atmosphere. The major gas CO\(_2\) can be reduced to a great extent through C sequestration mechanisms in the terrestrial sinks mainly the soil. Even when natural terrestrial sinks currently consume approximately 60 percent of the 8.6 Pg C Year\(^{-1}\) emitted, natural sink capability and intensity are not sufficiently large to assimilate all the expected anthropogenic CO\(_2\) released into the atmosphere during twenty-first century until the C-neutral energy sources take full effect. The sink potential of managed habitats (e.g. forests, farmland, and wetlands) can be increased by transitioning to judicious land use and implementing appropriate forestry, farm crops, and pasture management practices like various agricultural and sustainable practices; tillage operations, cover cropping, crop rotations, biochar, integrated nutrient management and microbial biomass management are the means in which CO\(_2\) emissions can be controlled. The deliberate management of biological processes will accelerate the CO\(_2\) sequestrating process, increase soil health, increase food production for the-population, and also increase the land sustainability as a resource, through the adoption of regulatory actions and policy incentive. Even so, for management systems to be successful, an integrated structure approach is highly required. There is a great scope in which mankind can control climate change where C sequestration has great potential.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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