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Carbon sequestration in agriculture for challenging climate change - An overview

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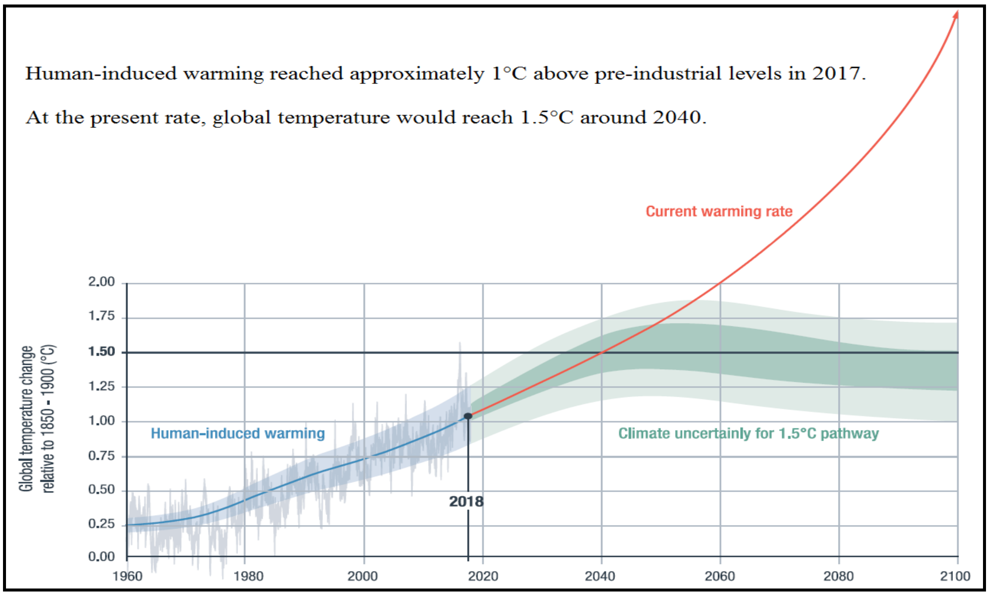
Abstract
The world struggles more to address the effect of global warming and changing climatic conditions due to the emission of greenhouse gases (GHGs). Among the GHGs, CO_2 is the most dominant gas, compared to methane and nitrous oxide. It accounts for about 50% of the total warming effect of all climate impact gases. One promising technology to reduce the CO_2 level in the atmosphere is carbon capture and sequestration (CCS), which consists of capturing CO_2 emissions from power plants and industrial sources and sequestering them in deep geologic formations for long periods of time. Carbon sequestration and storage in soils provide an important mean of decreasing GHGs in the atmosphere to mitigate predicted climate changes. Over one third of arable land is in agriculture globally and this will be a major component of using soils as a sink. The carbon sink capacity of the world's agricultural and degraded soils is 50 to 66% of the historic carbon loss of 42 to 78 gigatons (Gt) of carbon. An increase of 1 ton of soil carbon pool of degraded cropland soils may increase crop yield by 20-40 kg/ha for wheat, 10-20 kg/ha for maize, and 0.5-1 kg/ha for cowpea. As well as enhancing food security, carbon sequestration has the potential to offset fossil fuel emissions by 0.4 to 1.2 Gt of carbon per year, or 5 to 15% of the global fossil-fuel emissions. It is expected that in the next 50 years, Best Management Practices (BMPs) in agriculture could restore 5000 MMTC to the soil. Improved management of crop, grazing, and forest lands is estimated to potentially offset 30,000-60,000 million metric tons of the carbon released by fossil fuel combustion over the next 50 years.

Keywords: Carbon sequestration, greenhouse gas emissions, climate change, Best management practices, recommended management practices

Introduction
Climate change is a global threat that needs immediate action from global community. All the countries are being affected by climate change and its impact are even more in developing countries. If temperature is taken as a climate change indicator, human-generated emissions since the start of the Industrial Revolution (i.e. since "pre-industrial") have led to global warming of 1.0 °C. If these emissions continue at current rates, we are likely to reach 1.5°C of warming between 2030 and 2052 – an additional warming of 0.5 °C from today's level.



Source: Adapted from the Special Report on Global Warming of 1.5°C (IPCC, 2018)

The global warming as a result of increased GHGs emissions especially that of CO_2 will result in rapid effects (IPCC, 2007b) [11], as follows

1. Large scale disruption of forestry, agriculture and fisheries.
2. Extinction of many plant and animal species on land and oceans.
3. Changing rainfall and snowfall pattern.
4. Loss of huge tracts of coastal lands under rising seas as the oceans expands due to melting of polar ice.
5. Less assess to less reliable water supplies in many parts of the world.

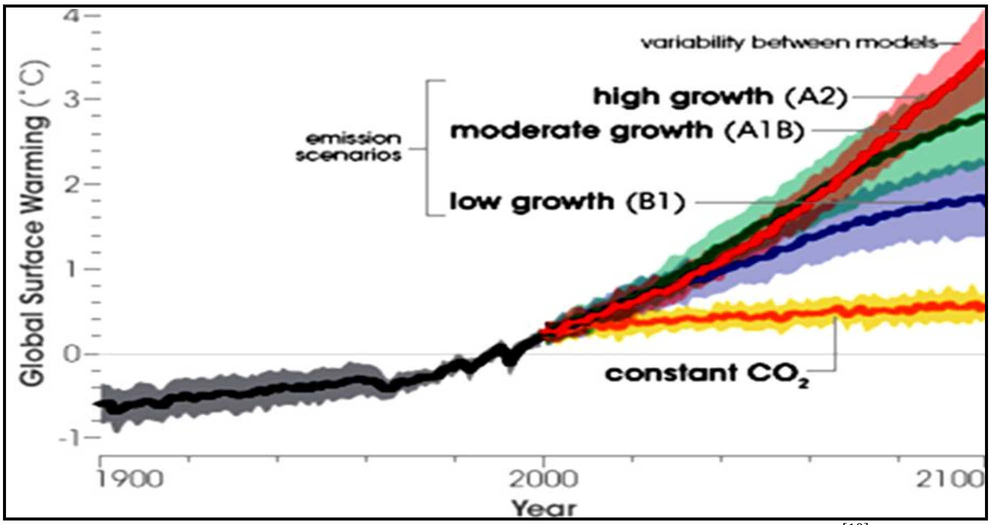
Increased global warming due to the rising levels of CO_2 pushed towards in search of new methods to reduce the atmospheric carbon level. This leads to the knowing the roles of soils as a carbon source or sink (Gupta and Rao, 1994) [8]. Carbon sequestration in soil and its biomass has been to be a key strategy to reduce atmospheric CO_2 (Powlson *et al.,* 2011) [23], suggested that increase in SOC normally termed as ‘accumulation’ and the term ‘sequestration’ can be used for the situations where there is an additional transfer of C from the atmosphere to contribute for climate change mitigation. The term *‘carbon sequestration’* is used to describe the process by which CO_2 is either removed from the atmosphere or diverted from the emission sources and stored in the ocean, terrestrial environments (vegetation, soils and sediments) and geological formations. Soil carbon sequestration will account for about 90% of the total global mitigation potential in agriculture by 2030 (Smith, 2008) [39]. Recent reports have investigated the potential of organic agriculture to reduce GHGs emissions (Rodale Institute, 2008) [24]. SOC sequestration on agricultural land decreases the costs of climate change mitigation while promoting increased food security. The objective of this paper is to discuss the agricultural practices and technological options for CO_2 sequestration to reduce the net rate of atmospheric concentration of CO_2.

Greenhouse gases and atmospheric temperature

Global warming refers to an average increase in the earth’s temperature, which in turn causes climate change. A warmer earth may lead to changes in rainfall patterns, a rise in sea level, and a wide range of impacts on plants, wildlife, and humans. When scientists talk about the issue of climate change, their concern is about global warming caused by anthropogenic activities. Carbon dioxide, CH_4, and N_2O in the atmosphere are the gases emitted by agricultural soils and are responsible for global warming as a consequence termed as “greenhouse effect”.

The outgoing solar radiation gets trapped by some of the radioactively active gases in the atmosphere such as water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), troposphere ozone (O_3), carbon monoxide (CO) and chlorofluorocarbon (CFC) which causes global warming. Over the past 150 years, the amount of carbon in the atmosphere has increased by 30% (Schlesinger, 1999) [25]. Most scientists believe there is a direct relationship between increased levels of carbon dioxide in the atmosphere and rising global temperatures.

The main sources of CO_2 emission are fossil fuel burning, natural decomposition of organic materials by micro organisms, agricultural and forestry activities, deforestation and land use change.



Source: NASA Earth Observatory, based on IPCC Fourth Assessment Report (2007a) [10].

Fig 1: Temperature projections to the year 2100, based on a range of emission scenarios and global climate models. The orange line (“constant CO_2”) projects global temperatures with GHGs concentrations stabilized at year 2000 levels.

Carbon sequestration

One proposed method to reduce atmospheric carbon dioxide is to increase the global storage of carbon in soils (carbon sequestration) (Schlesinger, 1999) [25]. An added benefit to this solution is the potential for simultaneous enhancement in agricultural production.

Carbon sequestration is the process of capture and long-term storage of atmospheric carbon dioxide to mitigate global warming and to avoid dangerous impacts of climate change. In other words, it also refers to the process of removing carbon from the atmosphere and depositing it in a reservoir. This carbon storages or reservoirs are also known as carbon pools. Carbon pool refers to a system or mechanism which has the capacity to accumulate or release. It can be natural or human induced. Examples are forest biomass, wood products, soils, and the atmosphere. Carbon pools in a forest are a complex mix of live and dead organic matter and minerals. Human induced carbon pools are geological storages of carbon dioxide.

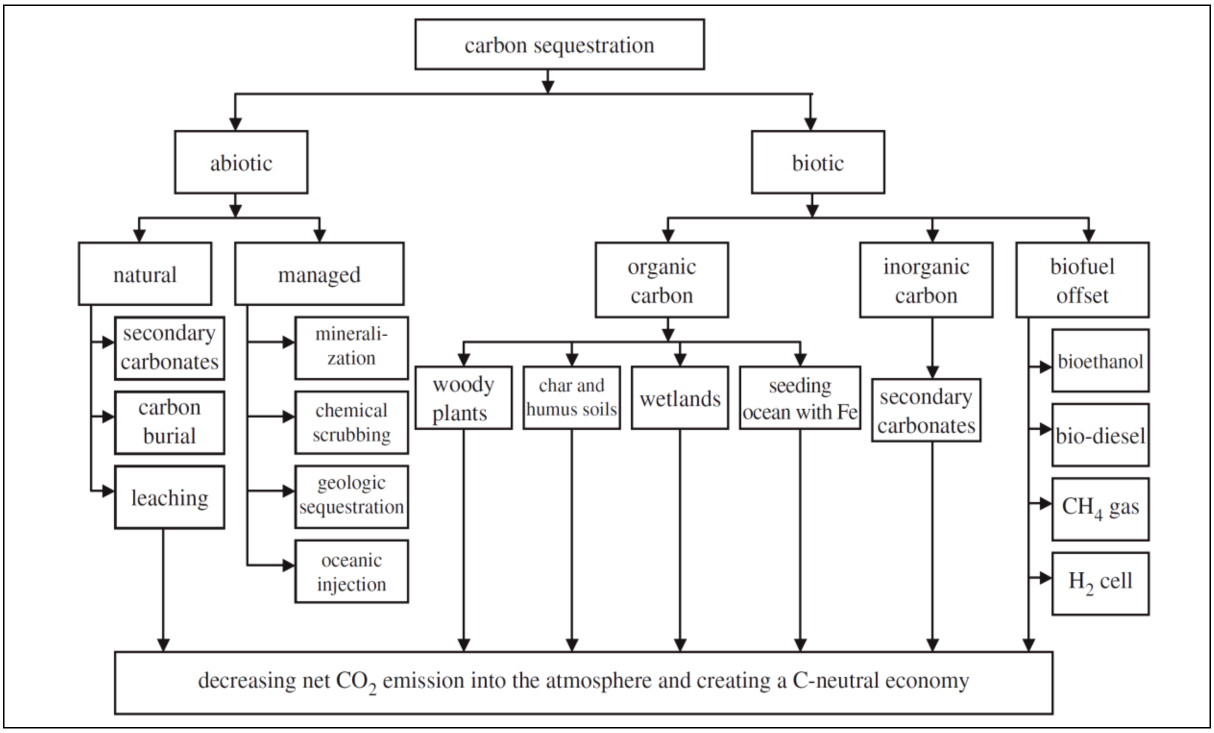


Fig 2: A wide range of processes and technological options for C sequestration in agricultural, industrial and natural ecosystems (Lal, 2008) [17].

Global carbon pools

The importance of atmospheric concentration of CO_2 on global temperature was recognized by Arrhenius (1896) [1] by the end of 19th century. Understanding the anomalous anthropogenic perturbation of global cycle of 20th century, it is important for developing viable strategies for mitigating climate change. Carbon cycle refers to the movement of carbon in its different forms and its exchange between the biosphere, atmosphere, oceans, and geosphere. The strong interactions between the atmospheric, pedologic and the biotic C pools comprise important components of the global carbon cycle (GCC). Understanding and managing these interactions form the basis of any strategy to sequester atmospheric CO_2 in the biotic and pedologic pools.

1. There are five global C pools, of which the largest oceanic pool is estimated at 38 000 Pg and is increasing at the rate of 2.3 Pg C yr^{-1}.
2. The geological C pool, comprising fossil fuels, is estimated at 4130 Pg, of which 85% is coal, 5.5% is oil and 3.3% is gas.
3. The third largest pool is pedologic, estimated at 2500 Pg to 1 m depth. It consists of two distinct components: soil organic carbon (SOC) pool estimated at 1550 Pg and soil inorganic carbon (SIC) pool at 950 Pg (Batjes, 1996)[2].
4. The fourth largest pool is the atmospheric pool comprising 760 Pg of CO_2–C, and increasing at the rate of 3.5 Pg C yr^{-1} or 0.46% yr^{-1}.
5. The smallest among the global C pools is the biotic pool estimated at 560 Pg. The pedologic and biotic C pools together are called the terrestrial C pool estimated at approximately 2860 Pg.

CO_2 sequestration in agriculture

Carbon sequestration in the agriculture sector refers to the capacity of agriculture lands and forests to remove carbon dioxide from the atmosphere. Carbon dioxide is absorbed by trees, plants and crops through photosynthesis and stored as carbon in biomass in tree trunks, branches, foliage and roots and soils (EPA, 2008) [6]. The ability of agriculture lands to store or sequester carbon depends on several factors including climate, soil type, type of crop or vegetation cover and management practices. The amount of carbon stored in soil organic matter is influenced by the addition of carbon from dead plant material and carbon losses from respiration, the decomposition process and both natural and human disturbance of the soil. Agricultural managers can strongly influence this dynamic in four ways:

1. Decreasing the level of soil disturbance (i.e. tillage) to enhance the physical protection of soil carbon in aggregates.
2. Increasing the mass and quality of plant and animal inputs to soils.
3. Improving soil microbial diversity and abundance.
4. Maintaining continuous living plant cover on soils year-round.

Farmers may be able to slow or even reverse the loss of carbon from their fields by employing farming practices that involve minimal disturbance of the soil and encourage carbon sequestration. Introducing plant diversity to crop rotations and using legume cover crops, which contain carbon compounds likely more resistant to microbial metabolism, could also increase the complexity and diversity of soil carbon, making it more stable (Wickings *et al*., 2014) [34]. Changes in crop land management have a high potential to sequester soil organic carbon, increases soil fertility, soil quality and food production and also mitigates climate change. Only maximizing carbon sequestration in croplands may not always be the best policy option; substitution of fossil fuels by using crop residues for bio energy may be as effective for reducing atmospheric CO_2.

Table 1: SOC sequestration rates under different land use management (Chan *et al.*, 2010) [3]

Agriculture activity	Management practice	Carbon sequestration rate (t C/ha/yr)
Cropping	Increase soil fertility	0.05 — 0.15
	Improve rotations	0.10 — 0.30
	Irrigation	0.05 — 0.15
	Eliminate fallows	0.10 — 0.30
Conservation tillage	Retain Stubble	
	0.40 Reduce tillage	
	Use no-till systems	
Addition of organic amendments	Add animal manure	0.10 — 1.10
	Add biosolids	1.00
Land conversion	Convert degraded cropland to pasture	0.80 — 1.10
Grazing	Use fertilizers	0.30
	Manage grazing time	0.35
	Irrigation	0.11
	Introduce legumes	0.75

Changes in land use, climate and farm management can have significant effects on carbon sequestration in cropland (Table 1.). Adaption of less intensive tillage practices works to sequester organic carbon in croplands mostly in warmer climates – but less so in colder climates. In general, SOC sequestration rate can be up to 0.5 to 1.5 t $ha^{-1}yr^{-1}$ in cool and humid climates and 0.05 to 0.5 t $ha^{-1}yr^{-1}$ in warm conditions and in arid regions (Lal, 2004) [15]. The rate of decomposition of SOM is generally higher in tropical than in temperate climates. However, crop species also play an important role in maintaining SOC pools, through the quality and quantity of the residues that are returned to the soil (Mandal *et al.*, 2007) [22]. Increasing the SOC pool by one Mg C ha^{-1} yr^{-1} can enhance agronomic production in developing countries by 32 and 11 million tons per year in case of cereals and food legumes respectively (Lal, 2011; Srinivasarao *et al*., 2012) [19, 30]. Fertilization generally increases carbon stocks in croplands since carbon inputs to soil increase, but this can be counteracted by increased N_2O emissions. Application of manure and crop residue return increases carbon stocks in cropland. Studies show that an increase in aridity, due to climate change, can cause significant decrease in soil organic carbon stocks. However, this could be mitigated by land use change. It has been estimated that carbon sequestration to the extent of 7.2 to 9.8 Tg C yr^{-1} (Table 2) can be achieved by arresting land degradation in India (Lal, 2004) [15].

Table 2: Carbon sequestration rates in different rainfed production systems of India (Lal, 2004) [15]

Degradation I [1¹(11	Area (M ha)	SOC sequestration rate (kg $ha^{-/}yr^{-i}$)	Total SO sequestratio I potential (Tg C yr
Water erosion	32.8 80-120		2.62-3.94
Wind erosion	10.8 40-60		0.43-0.65
Soil fertility decline	29.4 120-150		3.53-4.41
Waterlogging	3.1 40-60		0.12-0.19
Salinization	4.1 120-150		0.49-0.62
Lowering of water table	0.2 40-60		0.01-0.012
		Total	7.20-9.82

Climate change mitigation

Agriculture accounts for approximately 13% of total global anthropogenic emissions and is responsible for about 47% and 58% of total anthropogenic emissions of methane (CH_4) and nitrous oxide (N_2O). Besides CH_4 from enteric fermentation (32%), N_2O emissions from soils due to fertilization constitute the largest sources (38%) from agriculture (US-EPA, 2006; IPCC, 2007b; Stern, 2006) [32, 11, 31]. Several farming practices and technologies can reduce GHGs emissions and prevent climate change by enhancing carbon storage in soils (Table 3.) ; preserving existing soil carbon; and reducing carbon dioxide, methane and nitrous oxide emissions (Wani *et al.*, 2016) [33].

Table 3: Agricultural practices and benefits.

Conservation Practice	GHG Objectives	Additional Benefits
Crops		
Conservation tillage and reduced field pass intensity	Sequestration, emission reduction	Improves soil, water and air quality.
Efficient nutrient management	Sequestration emission reduction	Improves water quality. Saves efficient nutrient management Sequestration
Crop diversity through rotations and cover crops	Sequestration	Reduces erosion and water requirements.
Animals		
Manure management	Emission reduction	On-farm sources of biogas fuel and possibly electricity for large operations, provides nutrients for crops.
Rotational grazing and improved forage	Sequestration, emission reduction	Reduces water requirements. Helps
Feed management	Emission reduction	Reduces quantity of nutrients. Improves water quality. More efficient use of feed.

Source: NRCS. http://soils.usda.gov/survey/global_climate_change.html

Co-Benefits

Soil carbon plays important roles in maintaining soil structure, improving soil water retention, fostering healthy soil microbial communities (Wilson *et al.*, 2009) [35], and providing fertility for crops (Schmidt *et al.*, 2014) [26]. In addition to mitigating carbon emissions, increasing soil carbon can have profound effects on soil quality and agro ecosystem productivity.

Lal *et al.* (2010) [18] estimates the carbon sink capacity of the world's agricultural soils by enhanced management practices to be 21–51 Gt carbon, which is equivalent to all anthropogenic GHG emissions over 2–3 years. Many best soil management practices have been proven to help in sequestering soil carbon including, restoration of degraded soils and ecosystems, the adoption of recommended agricultural practices on prime land and retiring marginal agricultural lands to restorative land uses, conversion of croplands to grasslands, no-till farming, nutrient management, improved grazing, water conservation and harvesting, agro-forestry practices (Lal, 2010) [18].

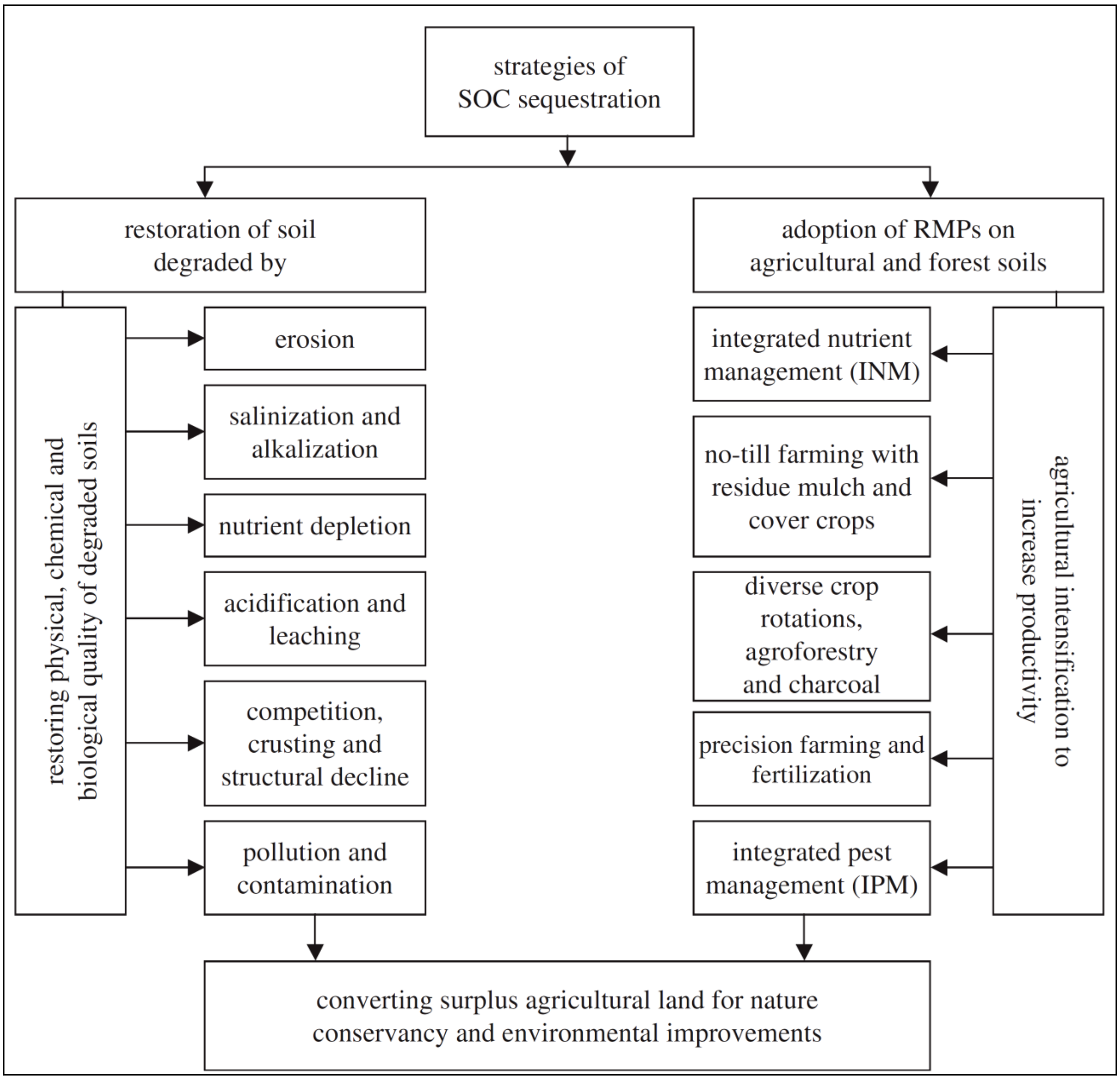


Fig 3: Management strategies for soil carbon sequestration through restoration of degraded soils and adoption of Recommended Management Practices (RMPs) on agricultural soils (Lal, 2008) [17].

It is expected that in the next 50 years, Best Management Practices (BMPs) in agriculture could restore 5000 MMTC to the soil (Lal, 2001) [14]. A soybean - wheat system in subtropical central India, the annual contribution of C from above ground biomass was about 22% for soybean and 32% for wheat (Kundu *et al.*, 2001) [13]. No tillage increased SOC significantly by 48.3 ± 9.9g cm^{-2} yr^{-1} over conventional tillage (Hooker *et al.*, 2005) [9]. Assuming 0.2 t C per ha per year for organic farming practices, the total carbon sequestration potential of the world's grassland would be 1.4 Gt per year at the current state, which is equivalent to about 25% of the annual GHG emissions from agriculture (Leibig *et al.*, 2005) [20]. Recent reports have investigated the potential of organic agriculture to reduce GHGs emissions (Rodale Institute, 2008) [24]. The concentration/pools of SOC can be enhanced through land-use conversion and adoption of RMPs in agricultural, pastoral and forestry ecosystems and restoration of degraded and drastically disturbed soils (Lal, 2008) [17] (Figure 3.).

If we are to avoid the economic and human consequences of severe climate change, we must significantly cut emissions of CO_2. On the whole, the chief challenges to reducing CO_2 emissions are not the technical ones, which, while not insignificant, are tractable; the real challenges are political and center on our ability to achieve intergovernmental cooperation between nations with different cultures and with competitive aspirations.

Future Climate

The Intergovernmental Panel on Climate Change (IPCC, 2001) [12] outlined what we should expect if CO_2 levels continue to rise unabated.

- Increased maximum and minimum temperatures: Heat stress on people, livestock and wildlife, Decreased cold-related morbidity Benefits to some crops, and increased risk to others
- Increased intense precipitation: Flooding, soil erosion
- Increased summer drying over mid-latitude continental interiors: Drought, impaired water resources, decreased crop yields
- Increase in tropical cyclone intensity: Danger to human life, increased coastal erosion, damage to coastal ecosystems
- Intensified drought and flooding associated with El Niño events
- Increased Asian summer monsoon variability: Increased flood and drought magnitude in temperate and tropical Asia
- Increased intensity of mid-latitude storms: Danger to human life, damage to property and coastal ecosystems
- Rising sea levels: Could rise by several meters over a few centuries if the Greenland ice sheet melts significantly.

Conclusion

The challenges of climate change can be efficiently overcome by the storage of carbon in terrestrial carbon sinks *viz.*, plants, plant products and soils for longer periods of time. Adoption of carbon sequestration measures can considerably reduce the rise in atmospheric CO_2 level. In order to sustain the storage of carbon under terrestrial systems adoption of BMPs should be followed in agricultural and other land ecosystems. While reducing the rate of enrichment of atmospheric concentration of CO_2, soil C sequestration improves and sustains biomass/agronomic productivity. Soil C sequestration is a strategy to achieve food security through improvement in soil quality. It is a by-product of the inevitable necessity of adopting RMPs for enhancing crop yields on a global scale. It has the potential to offset fossil-fuel emissions by 0.4 to 1.2 Gt C/year, or 5 to 15% of the global emissions. Soil organic carbon is an extremely valuable natural resource. Irrespective of the climate debate, the SOC stock must be restored, enhanced, and improved. By practicing SOC sequestration on agricultural land, target levels of GHG mitigation can be reduced at considerably lower carbon prices and less calorie loss, than mitigation scenarios that do not include SOC sequestration.

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