Soil and Environmental Management

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Abstract

Climate change is a variation in atmospheric properties due to natural and human activities over a long period of time. In the last few decades, there was a significant change in the gaseous composition of earth's atmosphere, mainly through increased energy use in industry and agriculture sectors, viz. deforestation, intensive cultivation, land use change, management practices, etc. These activities lead to increase the emission of carbon dioxide (CO_2), methane (CH_4), nitrous

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oxide (N_2O), etc., popularly known as the “greenhouse gases” (GHGs), and rise up the temperature. These GHGs cause regional and global changes in the climate-related parameters such as rainfall, soil moisture, and sea level. Intergovernmental Panel on Climate Change (IPCC) projected temperature rise from 0.5 to 1.2 ° C by 2020, 0.88 to 3.16 °C by 2050, and 1.56–5.44 °C by 2080 for India. To mitigate this climate change, among the different means, soil is also one of the key components of the agricultural production system, and it needs to be relooked in the view of the environment. Soil not only acts as a sink for GHGs but also as a source from agriculture. In this regard, concerted efforts are necessary for adverse climate change impact to reduce the vulnerability of agriculture. To meet out these issues, sources and mitigation options for individual gases from the soil are discussed in this chapter. Sources of CH_4 emission are due to microbial decomposition of soil organic matter (SOM) under the submerged condition, burning of crop residue, and the enteric fermentation. The N_2O is through fertilizers by the process of nitrification and denitrification. The major carbon (C) sources are tillage, burning of crop residue, and fossil fuel combustion. To overcome the emission of GHGs from the soil, the nature of the release of individual gas and its specific management can give an idea of sustaining soil health to safeguard the environment. Hence, reducing these GHGs emission from the soil through light to overcome the climate change effect. Reduction of CH_4 gas mainly from rice can be done by the adoption of intermittent irrigation, planting methods, fertilizer type, etc. Nitrification inhibitors from plant-derived organics such as neem oil, neem cake, and Karanja seed extract could also reduce the N_2O emission. Also, the demand-driven nitrogen (N) application using a leaf colour chart (LCC) reduces N_2O emission. By using legume crops in rotation helps to reduce the N_2O emission besides fixing long time C in the belowground. To reduce CO_2 emission from the agriculture, sequestering C through agroforestry system, conservation agriculture, perennial crops, etc. could be the effective strategies for assimilating and storing C for a long time in soil.

Keywords
Methane · Carbon dioxide · Nitrous oxide · Sources · Soil · Mitigation · Environment

Abbreviation

AMF	Arbuscular mycorrhizae fungi
C	C
CH_4	Methane
CO_2	C dioxide
FAO	Food and Agriculture Organization
Fig	Figure
FYM	Farmyard manure

GDP	Gross domestic production
Gg	Gigagram
GHG	Greenhouse gas
Gt	Gigatonne
GWP	Global warming potential
INM	Integrated Nutrient Management
IPCC	Intergovernmental Panel on Climate Change
LCC	Leaf colour chart
Mg	Megagram
MT	Metric tonnes
NICRA	National Initiative in Climate Resilient Agriculture
PM	Poultry manure
SIC	Soil inorganic matter
SOC	Soil organic matter
T	Tonne
Tg	Teragram
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
Yr	Year

1.1 Introduction

Agriculture is crucial to get ensured food, nutrition, and livelihood security of developing country like India. Two thirds of India's population depend on agriculture and account for a significant share in country's gross domestic product (GDP). Agriculture is the primary source for supplying raw materials for industry. Its linkage with other economic sectors has a multiplier effect on the entire economy of the country. The agricultural activities, viz. clearing of lands, crop cultivation, irrigation, livestock unit, fisheries, and other activities, have an impact on the GHG emission and lead to climate variability (Solomon et al. 2007; Yadav et al. 2017). Over the 250 years, CO_2 is the most important human-induced GHGs followed by CH_4 and N_2O. Based on the United Nations Framework Convention on Climate Change (UNFCCC) policy, India has planned to reduce 20% of GHG emission intensity by the year 2020. Current variations in rising sea level and glacier melting cause global climatic change. It increases the concentration of atmospheric GHG. These released from the earth surface cause the greenhouse effect, i.e. trapping of energy by the GHG in the atmosphere and leading to a rise in temperature. If it does not exist, cooling of the earth might have taken place, and ice would cover earth from pole to pole. For normal growth, development, and existence, the greenhouse effect is important. Past 4.65 million years of earth history, many times earth has warmed up naturally. But currently, due to human activity, rapid warming happened. Earth's average temperature is about 150o C (590 F), and it has risen during the last century by about 10 F. The rise would be 2.5–10.40 F by the year 2100. According to IPCC

(2007) fifth assessment report, warming of the atmosphere is not uniform and it is unequal. The main causes for increasing this global warming are by anthropogenic influences only. Gupta et al. (2002) also reported the same for developing country like Indian scenario. The climatic variation causes changes in the agricultural activity. Season variation expected during 2070 in a country like India is about 0.2–0.4 °C in Kharif and 1.1–4.5 °C during Rabi season (Pathak 2015).

The effect of GHGs measured as global warming potential (GWP) is a measure of the contribution of a given mass of greenhouse gas to global warming. GWP is calculated for a specific period of time and depends on the absorption of infrared radiation by a given species, spectral location of absorbing wavelengths, and species lifetime in the atmosphere. Thus, GWP for CO_2 is taken as 1, for CH_4 it is 25, and for N_2O it is 298. The GWP is calculated based on the 100-year time horizon. For example, GWP of one unit of CH_4 and one unit of N_2O is equal to 25 times and 298 times that of CO_2, respectively.

$$\mathrm{GWP} = \mathrm{CO_2} + \mathrm{CH_4} \times 25 + \mathrm{N_2O} \times 298$$

The current levels of CO_2, CH_4, and N_2O concentration are 401 ppm, 1789 ppb, and 321 ppb, and it increased from pre-industrial era (AD 1000–1750) to current time up to 73%, 45%, and 18%, respectively (Solomon et al. 2007; Meena and Meena 2017). In a developing country like India, a high level of fertilizer usage, other agricultural inputs, and increasing livestock population are the major sources of GHG emissions from agriculture. However, the contribution of Indian agriculture to total GHG emission has been decreased from 33% in 1970 to 15% in 2014. But, the unavoidable faster growth rate of industry, transport and energy sector has the possibility to reduce GHGs. Presently India contributes 5% of world GHG emission of 50 billion tonnes of CO_2 equivalent. Indian energy sector contributes 65% followed by 18% by agriculture and 16% by industry. Within agriculture, enteric fermentation share is 56%, followed by 23% from soil and 18% from rice fields and remaining 1% from on-farm burning of crop residues and 1% from manure management (Pathak 2015). The impact of climate change indicated an alarming bell on fertilizer use and its efficiency, organic C retention, soil erosion, etc., which causes severe droughts and floods and will decline the arable areas (Gupta et al. 2002; Yadav et al. 2018). It has its adverse effect on soil properties too, viz. reduction in quality and quantity of organic C, slow rate of decomposition by high C:N ratio, increased gaseous losses of N due to high soil temperature, etc. (Pathak 2015; Ram and Meena 2014).

Thus, global warming is an important issue. The ways and means of mitigating the GHGs responsible for global warming are essential. Among the different strategies, agricultural practices also one to mitigate climate change through sequestering C in soil and reducing the emission of CH_4 and N_2O from the soil through land use changes and other management practices. The cultural practices such as residue mulching and reduced tillage or zero tillage encourage the soil C build-up. The proper management of fertilizers, manures, and irrigation can reduce the emissions of N_2O and CH_4. These options could reduce global warming besides improving soil fertility. In addition to that, the substitution of fossil fuel by biofuels for energy production also possibly reduced the GHG emission. The other options like changing cropping pattern by including legumes, perennials, or deep root systems could increase the C storage in soil.

Policies and incentives are essential to encourage the farmers to adopt these mitigation strategies besides the benefits of improved soil fertility. Managed soils are the prime source of N_2O and CH_4. Jain et al. (2014) reported that GWP has been ranged from 3500 to 3700 kg CO_2 eq/ha in continuously flooded rice and the rice grown with intermittent flooding released 900–1050 kg CO_2 eq/ha, whereas the other crops like wheat, maize, millets, oilseeds, pulses, and vegetables contribute to 340–450, 320–365, 230–250, 220–275, 180–240, and 440–575 kg CO_2 eq/ha, respectively. Through agriculture, the emission of GHGs could be mitigated cost-effectively by adopting low C technologies and management practices. For example, the practices of improving the efficiency of N often reduce N_2O emission. In agriculture, any practice that slows down the release of C from the soil could also act as a sink of C.

Soil contributes a major share of 37% GHG emissions, and it could be reduced by sequestering some CO_2 in soil and in turn improve soil fertility and productivity by improved management practices. According to IPCC (2013) report, 1500 billion tonnes of C is stored in the soil which is double the amount of C in the atmosphere. 1.2 billion tonnes of soil C storage is possible in agriculture (IPCC 2014). Lal (2006) added that 24–40 million tonnes of more production of grain is possible every year in Africa, Asia, and South America by storing SOC pool of 1 tonne per year per hectare of land.

By considering the above points in mind, sustainable management of soil and environment topic is discussed in this paper by collecting the literature from the published papers and the experiences. This chapter present a way that, the sources of GHGs, mitigation of GHGs, and new concept of mitigating climate change to managing the soil and environment.

1.2 Sources of Methane Emission from Agricultural Soil

Mostly CH_4 is emitted from agriculture by rice cultivation next to ruminant emission. CH_4 is produced under anaerobic condition during microbial decomposition of SOM accompanied by favourable conditions, viz. continues submergence, high level of C content, and fresh organic manure use in puddled soil. Crop residue burning especially in situ conditions also contributes to CH_4 budget. Over 100 years, GWP of methane is about 25 times powerful than CO_2 (Forster et al. 2007; Meena et al. 2018). Globally CH_4 contributes about 16% of the GWP, and its contribution triples since the pre-industrial times and now at present seems to be static or decreasing. CH_4 emission from the cultivation of rice differed widely and reported range (Chen et al. 2015; Sofi et al. 2018; Meena et al. 2015d) is 39 and 112 Tg CH_4/year. In the Asian region, CH_4 emission accounts for 25.1 Tg/year, of which India emitted 5.88 Tg and China emitted 7.67 Tg. Yan et al. (2003) reported a CH_4 emission of 28.2 Tg/year from rice fields.

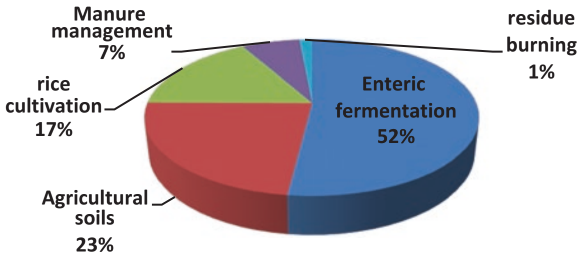

Fig. 1.1 Relative contribution of agricultural components to CH_4 emission (Bhatia et al. 2013)

Based on several estimates of CH_4 emission from rice soils, it has been rationalized from the previous estimation of 37.5Mt to 3.5Mt (Bhatia et al. 2013; Yadav et al. 2018a). They also added that similar trend of CH_4 emission data reported by the global atmospheric research, FAO and United States Environmental Protection Agency (USEPA), and UNFCCC during 2010. The relative contribution of agricultural components to CH_4 emission indicated that enteric fermentation contributes 211 MT of CO_2 equivalent of GWP followed by agricultural soil (94 MT of CO_2 equivalent), rice cultivation (68 MT of CO_2 equivalent), manure management (MT of CO_2 equivalent), and crop residue burning (6 MT of CO_2 equivalent) (Fig.1.1).

In rice fields CH_4 presents as a gaseous form or dissolved one (Tokida et al. 2005; Meena et al. 2016). According to Strack and Waddington (2008), 33–38% of CH_4 is in the gaseous phase. Green (2013) reported that the amount of dissolved CH_4 is low due to its low solubility (17 mg/lit) at 350C in water and lack of ionic form. The organisms, viz. methanogens, methanotrophs, and atmospheric soil CH_4 link, are responsible for the regulation of the total soil CH_4 cycle. There are three possible mechanisms by which CH_4 is emitted to the atmosphere, viz. diffusion, ebullition, and plant-mediated transport. The diffusion is a slow process of CH_4 emission, physical in nature, and less in amount of flux from the soil due to less soluble in nature. The diffusion process is very low in clay soil and high in sandy soils due to pores. According to Neue (1993), deep water rice diffusion is active in the upper column of water. Diffusion also limits the plant-mediated CH_4 transport by enriching the plant rhizosphere at a threshold level of CH_4 concentration.

Another process of CH_4 emission from rice soil is ebullition in which CH_4 transported in the form of bubbles (Rosenberry et al. 2006; Meena et al. 2015; Yadav et al. 2017a). It is a common mechanism and thought to be a faster process than diffusion. High organic matter content favours this process. Schutz et al. (1989) reported that ebullition process contributes 4–100% (depend on season) of CH_4 emission from a rice field in Italy. Butterbach-bahl et al. (1997) reported that 10% of CH_4 is emitted through ebullition process during the first few weeks. According to Tokida et al. (2013), a significant total amount of CH_4 is emitted from rice field, i.e. 26–45% at panicle initiation and 60–68% at heading stage through (based on bubble volume) ebullition only. Another important process of CH_4 emission is through biological means, i.e. by aerenchymatous tissue. Aerenchyma's main function in the plant is the transportation of oxygen for root respiration in rice. Aerenchyma is a modified parenchymatous tissue with air vacuoles to make up the

Table 1.1 Seasonal CH_4 emission from rice fields at different locations in India

Location	Methane (kg ha^{-1})	No. of observations	Average (kg ha^{-1})
Nadia, West Bengal	108–290	3	158
Purulia, West Bengal	110	1	110
Barrackpore, West Bengal	18–630	3	222
Jorhat, Assam	97–460	5	175
Tezpur, Assam	10–14	2	11.7
North 24 Parganas West Bengal	145–462	2	305
Cuttack, Orissa	7–303	44	91
Bhubaneshwar, Orissa	140–186	2	163
New Delhi	10–221	68	39
Allahabad, Uttar Pradesh	5	1	5
Kumarganj, Uttar Pradesh	20	1	20
Maruteru, Andhra Pradesh	150	1	150
Madras, Tamil Nadu	110–182	2	149
Trichur, Kerala	37	1	37
Trivandrum, Kerala	90	1	90
Kasindra, Gujarat	120	1	120
Pant Nagar, Uttarakhand	54–114	4	79
Kamal, Haryana	64–100	2	81
Varanasi, Uttar Pradesh	0.1–261	15	117
Raipur, Madhya Pradesh	4–109	6	34
Ludhiana, Punjab	452–1650	5	875

Pathak (2015)

plant to adopt flooded condition (Armstrong 1978). According to Setyanto et al. (2016), plant-mediated transport contributes 80–90% of the CH_4 flux from the rice field. Nouchi et al. (1990) reported that primarily CH_4 is released through the micropores in the leaf sheath of lower leaf and released through stomata in the leaf hole. Pathak (2015) reported the seasonal CH_4 emission from rice fields at different locations of India (Table 1.1).

1.3 Sources of Nitrous Oxide Emission from Agricultural Soil

N_2O is a gaseous intermediate in the reaction sequence of denitrification and by-product of nitrification in the soil. The availability of inorganic N is the main factor for these reactions which is applied through external application of N by synthetic or organic fertilizers (Fig. 1.2). Emission of N_2O from Indian soils was 259 Gg and 45 Gg, respectively, from direct and indirect means. The largest source for N_2O emission is fertilizer which contributes 77% to direct N_2O emission (Pathak 2015).

Six percent of the anthropogenic greenhouse gas emission is contributed by N_2O and increasing by about 0.25% per year. During the pre-industrial era, N_2O concentrations recorded was 270 ppb, and it increased up to 319 ppb in 2005. According to

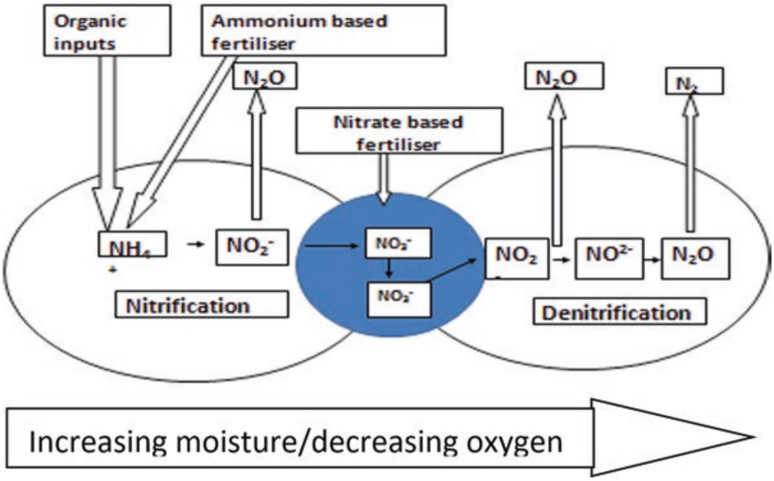

Fig. 1.2 *Pathways* of N_2O emission

IPCC (1996) and Denman et al. (2007), N_2O emission range from 14.7 to 17.7 Tg N_2O/year. Mostly more than 50% of the N_2O emissions are from agriculture and biomass burning. Fertilized arable land contributes at 3.3 Tg N_2O/year and 1.4 Tg NO-N/year globally (Stehfest and Bouwman 2006). Based on IPCC report, fertilizer-induced N_2O emissions (at the rate of 1.25 + 1% of the N) ranged between 0.77% for rice and 2.76% for maize.

1.4 Sources of Carbon Dioxide Emission from Agricultural Soil

In agriculture, soil management practices such as tillage, land use, fertilizer, manure application, crop burning, etc. contribute to CO_2 production. These practices trigger the decomposition of soil organic matter and release CO_2 gas. Tillage breaks up soil aggregates and exposes the surface area of organic material, promoting their decomposition. Fuel usage in different agricultural operations and crop residue burning are other sources of C emission. Off-farm production of CO_2 during the manufacturing of fertilizers, pesticides, and farm implements is also a source for global warming. The data pertaining to C produced by various agricultural practices are given in Table 1.2.

CO_2 globally cycles among atmosphere, ocean, and lithosphere. The atmosphere contains C as CO_2 of 785 Gt which is equal to approximately 15 t C above each hectare of the earth. The total amount of CO_2 exchanged between the land surface and the atmosphere is approximately 120 Gt C/year. From this, half of it is released through respiration by plants (Denman et al. 2007; Meena et al. 2017).

Atmospheric CO_2 concentration globally increased by 110 ppm to 385 ppm in 2008 from 275 ppm during the pre-industrial era. According to Denman et al.

Table 1.2 C produced by various agricultural inputs and practices

Inputs	Pretty et al. (2003)	Lal (2004)
Fertilizers	kg C/kg	kg C/kg
N	0.98–1.57	0.9–1.8
Phosphorus	0.11–0.17	0.1–0.3
Potassium	0.10–0.15	0.1–0.2
Lime		0.03–0.23
Pesticides	kg C/kg	kg C/kg
Herbicides	3.57–5.71	6.3
Fungicides	1.38–2.21	3.9
Insecticides	2.99–4.48	5.1
Agricultural operations		(Lal 2004)
One spray		1–1.4
Tillage operations		2–20
Drilling or seeding		2–4
Combine harvesting		6–12
Conventional tillage		35.3
Minimum tillage		7.9
No-tillage for seed bed preparation		5.8
Pumped irrigation using sprinkler		129

(2007), atmospheric CO_2 load increased at the rate of 4.1 Gt C/year during 2004–2005. During the 1900s, land use changes and management estimated to contribute 6–39% of the CO_2 growth rate. While converting natural ecosystem, the agriculture causes depletion of SOC pool by 60% in temperate regions and 75% in cultivated soils in tropics. Benbi et al. (2012) reported that land use and management practice has a greater role in CO_2 emission than fossil fuel burning until the beginning of the twentieth century.

Based on IPCC values, globally SOC pool consists of 2500 gigatonnes (Gt) which include 1550 Gt of SOC and 950 Gt of soil inorganic C (SIC). SOC pool is 3.3 times greater than the atmospheric pool (760 Gt) and 4.5 times that of the biotic pool (560 Gt). The SOC stock of 1 m depth ranges from higher side 800 t/ha in organic soils to 30 t/ha in an arid climate with an average value of 50–150 t/ha.

1.5 Mitigation of Methane Emission

Among the different agricultural ecosystems, wetland ecosystem is the prime source for methane emission. A large amount of CH_4 emission in rice fields generated through methanogenesis under anaerobic conditions and low oxidation-reduction potentials (Mer and Roger 2001; Meena et al. 2017a). In that case, reducing methanogenesis in rice soils or improving CH_4 oxidation in well-aerated soil will be the best management strategy for mitigating CH_4. Its emission also depends on organic matter incorporation (crop residues). Increases in CH_4 production were reported under rice farming when straw was added from 0 up to 7 t/ha (CH_4 emission from

100 to 500 kg/ha/year) (Sanchis et al. 2008; Mitran et al. 2018; Yadav et al. 2017b). For managing rice straw in the field, recommended practices are composting of rice straw, straw burning under controlled condition, and biochar production using rice straw as a substrate for other products production. The other agronomic practices which could reduce the CH_4 emission are midseason drainage and intermittent water supply which prevent the development of soil reductive condition. GHG emission reduced to 50–90% compared to continuous flooding by draining one or two times during rice growth period (Pathak et al. 2015). Gupta et al. (2002) conducted a study in Indian condition and reported that CH_4 flux reduced to 6.9 g/m2 from 15.3 g/m2 for continuous flooding. CH_4 emission also depends on the source of fertilizer used. Hence, water management and fertilizer use are important components controlling the CH_4 flux. The intermittent flooding or alternate wetting and drying has been reported by many scientists to decrease CH_4 emission. Pathak et al. (2013) reported that by changing the water management from present practice to the above practice in all the rice growing areas of Indian country could reduce the national CH_4 flux by 40% from 0.79 Tg to 0.49 Tg. They also added that intermitted flooding increased the N_2O fluxes to 14.27 Gg from 13.46 Gg N/year. Since the N_2O possesses higher GWP, the increased N_2O might be reducing the benefit of the decreasing CH_4 and CO_2 fluxes. Anyway, GWP of irrigated rice ecosystem of India has reduced by 13% from 154 Tg to 134 Tg CO_2 equivalent/year. Direct seeding of rice and system of rice intensification could be the potential options for CH_4 emission reduction.

Type, rate, and fertilizer application methods to rice influence the CH_4 emission. Dong et al. (2011) reported that 50% of CH_4 emission reduction is possible by proper N management in rice. Ammonium-based N fertilizers have the potential to reduce CH_4 emission than urea (Linquist et al. 2012; Meena et al. 2018a). Ali et al. (2012) reported that application of ammonium sulphate to the rice field reduced the CH_4 emission by 23%. But 25–36% was reported by Corton et al. (2000). Application of silicate fertilizer at the rate of 10 t/ha could mitigate CH_4 emission by 28% (Ali et al. 2008; Varma et al. 2017). Decreased CH_4 emission is also noticed by the researchers with ammonium nitrate application. Application of K could reduce CH_4 emission by reducing soil redox potential and stimulating CH_4 oxidation (Hussain et al. 2015; Meena et al. 2014). Ali et al. (2008) reported that application of 30 kg K/ha reduced CH_4 emission by 49% as compared to no K application. The organics like biochar reduced the CH_4 emission in rice compared to farmyard manure application (Pandey et al. 2014). Depnath et al. (1996) observed that biogas slurry as manure resulted in reducing CH_4 emission than FYM. Azolla and cyanobacteria facilitate the CH_4 reduction by increasing dissolved oxygen and reducing redox potential and promoting CH_4 oxidation at the soil-water interface (Hanson and Hanson 1996). Application of ammonium sulphate reduced the CH_4 emission by 30–60% compared with urea by maintaining favourable redox potential (Mosier et al. 1998). The picture given below (Fig. 1.3) lists the various practices which are reducing/producing the CH_4 emission in rice fields.

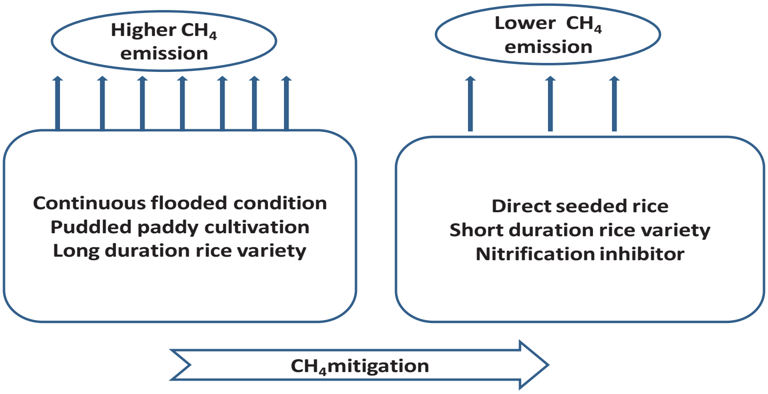

Fig. 1.3 Ways of CH_4 emission from rice fields

1.6 Mitigation of Nitrous Oxide

Use of Nous fertilizer alone contributes to more than 70% of the N_2O emission. Reducing N usage could reduce the N_2O emission. One of the processes to mitigate N_2O emission is by improving the efficiency of N use. The synchronized N supply with crop demand, use of nitrification inhibitors, and fertigation through drip or sprinkler irrigation can reduce N_2O emissions. According to Pathak et al. (2015), among the nitrification inhibitors, Nimin has higher mitigation potential (25–35%), and the neem cake has lower mitigation potential of 10–21%. More N_2O is emitted from the arable soils than any other human-induced sources. Jain et al. (2014) reported that reducing this N_2O emission and GWP by about 11–14% is possible for mitigation opportunity (Bhatia et al. 2012; Varma et al. 2017a; Jain et al. 2014). On average, about 1% of the applied N is directly emitted as N_2O. Miller et al. (2010) reported that corn farmers could reduce N_2O loss by 50% by adopting conservative fertilizer practices. They also proposed conservation practices such as the application of N match with crop demand, application of N fertilizer based on the natural pattern of soil fertility, an application within the root zone rather than on soil broadcasting, and applying fertilizer close to crop need. But all types of N fertilizer with coatings could delay its dissolution capacity and in turn reduce N_2O emission.

Leaf colour chart can be used for synchronized N application with crop demand to reduce GHG emission. Application of N based on the LCC method reduced the N_2O emission in wheat and rice fields. At LCC < 4, application of 120 kg N per hectare decreased 16% of N_2O emission and 11% of CH_4 over conventional application of urea in rice. The GWP were 13.692 and 12.395 kg CO_2/ha in conventional and LCC < 4 N application, respectively (Bhatia et al. 2013). They also added that, in the rice-wheat system, GWP reduced by 10.5% for LCC-based urea application. Soil fertilized with nanofertilizer N (NH4+ form) with zeolite (carrier) recorded lower N_2O emission (1.8 mg/m2/day) than conventional fertilizer (2.7 mg/m2/day). Soil fertilized with NO3 form of N revealed lower CH_4 emission of 34.8 mg/m2/day than conventional fertilizer (36.8 mg/m2/day) (Pathak 2015). Legume-based cropping system also contributes to reducing the N_2O emission. Legumes naturally fix the high amount of N through the process of BNF.

1.7 Mitigation of Carbon Dioxide Emission

CO_2 is emitted into the atmosphere in several ways. Energy factors by fuel usage are the largest CO_2 emission source. The main strategy to lower CO_2 includes developing low C fuel or biofuel and reducing fuel usage and sequestering C through natural ways. Practically C can be stored by sequestration in soil and vegetation. According to Burney et al. (2010), intensive agriculture improved the C sequestration because of the high amount of crop residues of root biomass and exudates returned to the soil as C source. Benbi and Brar (2009) reported that intensive agriculture enhanced the soil organic C by 38% by reducing CO_2 emission in the 25 years study of the Indian situation. The indirect emission of CO_2 can be reduced by improving the use efficiency of energy-based inputs like fertilizers, pesticides, and irrigation. Once SOC is sequestered, it must be retained and should not return to the atmosphere quickly, i.e. called C sequestration, and it depends on the mean residence time (MRT) of C. It is the long-term storage of C in the soil as well as the capacity of soils to remove CO_2 from the atmosphere. There are five important global C pools. Among those, oceanic pool (38,000 pg) is the largest and then geological pool (5000 pg), coal pool (4000 pg), oil and gas pool (500 Pg), pedological pool (SOC 2500 pg), biotic pool (560 pg), and atmospheric pool (760 pg). According to Lal (2004), the average lifetime of C in the atmosphere is 5 years, vegetation is 10 years, soil is 35 years, and sea is 100 years. The CO_2 is fixed by plants, (leaf litter, roots, and root exudates), and the activity of soil fauna transforms these substrates into more resistant organic components called humus which is a highly resistant material (Fig. 1.4). Management of soil to perfect C storage includes minimum tillage, crop residue, mulching, applying slow degradable C such as biochar, and other C sequestration measures.

The MRT of SOC depends on the SOC pool and flux which may be influenced by soil management and land use. According to Lal (2016), the MRT of SOC is affected by so many factors, i.e. the stabilization of soil C in soil aggregates, clay-humus complex formation, subsoil storage, slower microbial decomposition, the creation of high energy bonds, the formation of recalcitrant substances, and complexation into long-chain polymers. Benbi et al. (1998) reported that application of FYM along with NPK to rice sequestered on an average 0.17/C/ha/year. Pathak et al. (2015) reported that organics combined with fertilizers sequestered more C. According to Benbi et al. (2012), 8–21% of the occluded C is sequestered in the soil based on soil type and climatic conditions. The addition of crop residues, animal manure, and compost improves the formation of macroaggregates and stores inside the aggregates (Benbi and Senapati 2010; Kakraliya et al. 2018).

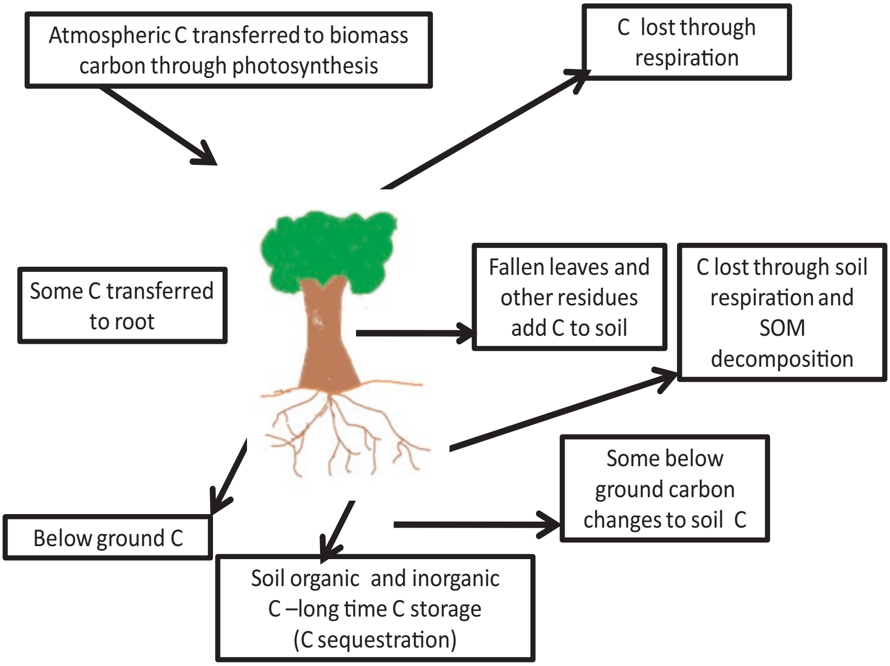

Fig. 1.4 Process of C sequestration

Soil under rice-based system is found to sequester 70% more C than a maize-wheat system. West and Post (2002) also revealed that the change of tillage from conventional to no-till could sequester 57–74 g C/m2/year.

The effect of crop rotation on C sequestration depends on crop species and crop residue management. Cropping systems and choosing of crops also play a role to improve SOC which is a way to remove C from atmosphere and store for a long time. Introducing perennial crops to crop rotation enhances the SOC stock and quality (Pellegrino et al. 2007; Meena et al. 2015c). Including legume in the cropping sequence does not have a significant effect on C sequestration due to its low biomass production. However, the highest potential of this type of cropping sequence with avoidance of Nous fertilizer consequently reduces the other GHG, i.e. N_2O emission. Crop rotation involving legumes is included in the European Union's Common Agricultural Policy's greening programme requirements with incentives encouraging the farmer's implementation. Aguilera et al. (2013) reported an average SOC sequestration rate of 0.27 Mg//ha/year for all types of cover crops in a meta-analysis of Mediterranean cropping system. Long-duration crops will sequester high C and restore soil fertility. The effect of short-duration crops does not have any significant effect with short-term studies. However, the positive effect of crops on C storage is observed with long-term studies (>15 years) if crop biomass is properly recycled. Use of crops has been considered as a means to improve labile C pools by incorporating plant biomass. Legume cultivation in yearly rotation reduces to greenhouse gas emission from N fertilizer manufacturing.

According to Bama et al. (2017a), bhendi-maize cropping sequence registered higher SOC stock of 11.24 t/ha/year (Fig. 1.5). They also stated that, irrespective of manures and cropping sequence, minimum tillage recorded higher SOC stock of 10.92 t/ha/year than conventional tillage of 10.72 t/ha/year. Mulching with 75% recommended dose of fertilizers and 25% N through organics revealed higher C stock than mulch with 100% recommended dose of fertilizers. They also added that, in the cotton green gram cropping sequences, irrespective of mulching and fertilizer treatments, minimum tillage recorded higher SOC content (5.15 g/kg) than conventional tillage (5.0 g/kg). Among the manurial treatments, the higher SOC of 5.30 g/kg was recorded in the treatment with mulch +75% recommended dose of N through fertilizers and 25% N through organics.

The soil C stock value indicated the capacity of the soil to hold C. Bama et al. (2017b) reported in another study that a higher value of total C is recorded in bhendi-maize+cowpea-sunflower sequence that might be due to the addition of legume crop sequence (Fig. 1.6 and Table 1.3). The lowest TOC was recorded in cotton and sunflower cropping sequence (7365 mg/kg) due to the exhaustive nature of crops. Smyrna (2016) also reported the same trend of the result.

According to Bama and Babu (2016), forages particularly grass-type fodder contribute to C sequestration in terms of a long-time C storage from roots, i.e. belowground portion, and it can saturate C level quickly wherever the climate change mitigation is essential. Among the various forage crops, Cumbu Napier hybrid grass removed higher C removal by biomass, and among the sources, farmyard manure application sequestered more C in the belowground. Bama et al. (2017c) reported that zero tillage recorded higher C stock value of 13.12 t/ha followed by minimum tillage (12.79 t/ha) (Fig. 1.7).

Bama and Somasundaram (2017) revealed that green manure-brinjal-sunflower cropping sequence registered higher soil organic C value (7257 mg/kg). Irrespective of the cropping system, organics (100%) alone revealed higher SOC (7143 mg/kg) (Fig. 1.8).

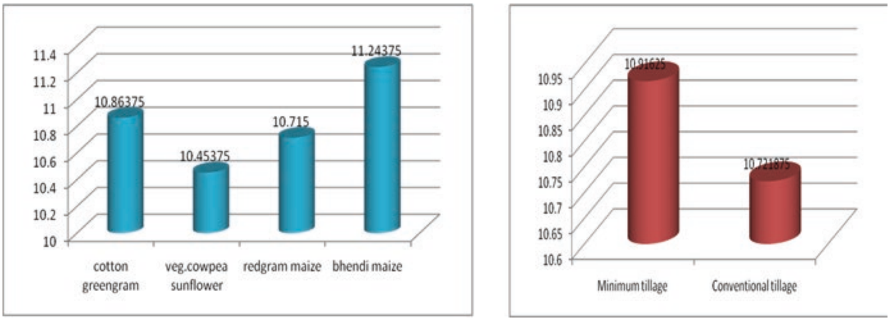

Fig. 1.5 Soil C stock as influenced by different cropping sequences and tillage practices (Bama et al. 2017a)

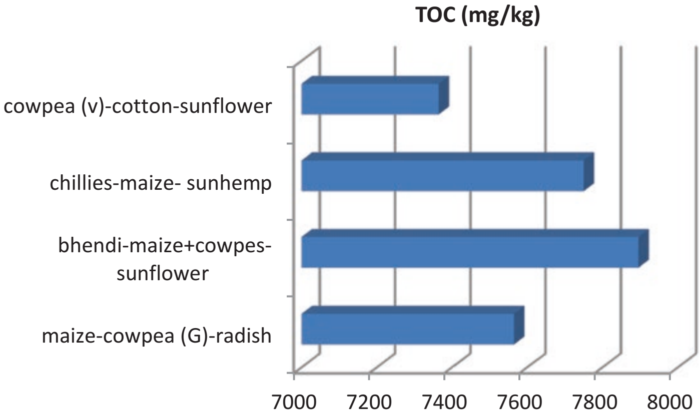

Fig. 1.6 Influence of different cropping sequences on total soil C (Bama et al. 2017b)

Table 1.3 Influence of different cropping sequences on total soil C

Cropping pattern	TOC (mg/kg)
Maize-cowpea (g)-radish	7565
Bhendi-maize+cowpea-sunflower	7895
Chillies-maize-sunn hemp	7750
Cowpea (v)-cotton-sunflower	7365
CD (5%)	425

Bama et al. (2017b)

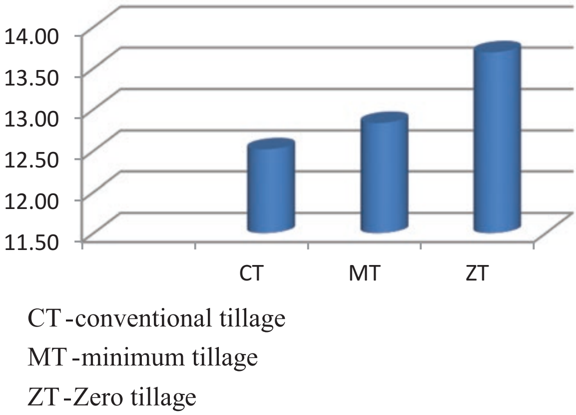

Fig. 1.7 Soil C stock (t/ha) under tillage practices in a cotton-maize cropping sequence (Bama et al. 2017c). *CT* conventional tillage, *MT* minimum tillage, *ZT* zero tillage

Bama (2014, 2017) reported a drastic improvement in the organic C status of the soil by the application of organic manures in the Cumbu Napier hybrid grass grown soil, i.e. higher organic C content of 1.28% in the FYM applied on N equivalent basis than other organic sources over an initial C status of 0.71% only. The increase in organic C is attributed to direct addition of organic manure in the soil which

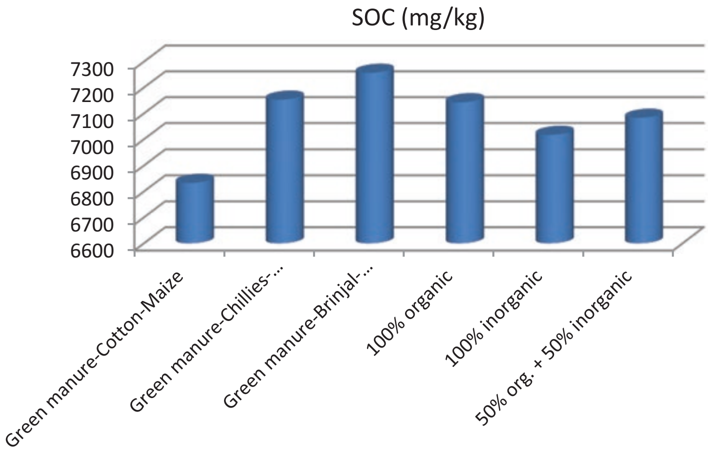

Fig. 1.8 Influence of intensive cropping and fertilization on SOC (mg/kg) (Bama and Somasundaram 2017)

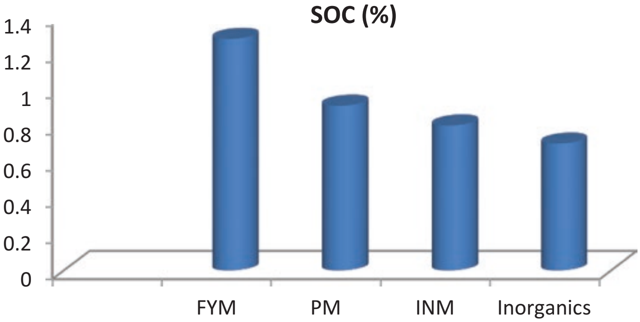

Fig. 1.9 Soil organic C as influenced by Cumbu Napier grown soil under different nutrient sources (Bama 2017)

stimulated the growth and activity of microorganisms and also due to better root growth resulting in the higher production of biomass, crop stubbles, and residues. Soil organic C as influenced by Cumbu Napier grown soil under different nutrient sources is given (Fig. 1.9).

Bama and Babu (2016) reported that Cumbu Napier grass had higher C sequestration potential of above-ground biomass which removed 336.7 t CO_2/ha than multicut fodder sorghum (148.7 t CO_2/ha) (Fig. 1.10 and Table 1.4). They also reported that, the belowground biomass C removal in Cumbu Napier grass (7.73 t CO_2/ha) from the atmosphere than Lucerne (4.21 t CO_2/ha). The soil physical properties and microbial populations were also favourable in the grass-type fodder. In addition, the Cumbu Napier fodder crop stored 9.2 g/kg of SOC over initial SOC status of 6.5 g/kg, followed by multicut fodder sorghum which accumulated 8.7 g/kg. The FYM

Fig. 1.10 Carbon dioxide removal (t/ha/3 years) by the above-ground biomass of various fodder crops (Bama and Babu 2016)

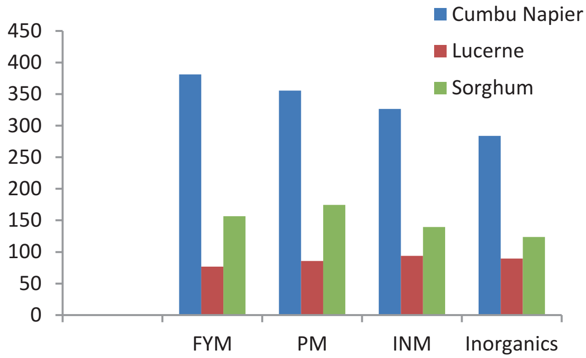

Table 1.4 Carbon dioxide removal (t/ha/3 years) by the above-ground biomass of various fodder crops

Treatments	Cumbu Napier	Lucerne	Sorghum	Mean
S1-FYM	381.3	76.7	156.5	204.8
S2-PM	355.4	85.5	174.5	205.1
S3-INM	326.4	93.9	139.7	186.7
S4-inorganics	283.7	89.6	123.9	165.7
Total	336.7	86.4	148.7	

FYM farmyard manure, *PM* poultry manure, *INM* integrated nutrient management

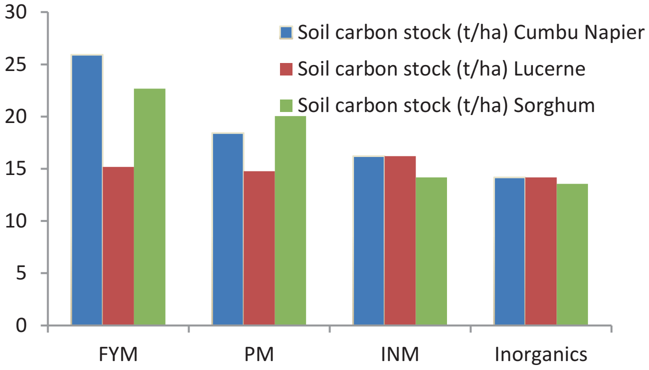

Fig. 1.11 Soil C stock (t/ha) as influenced by various fodder crops under different nutrient sources (Bama and Babu 2016)

application to Lucerne and Cumbu Napier hybrid grass improved the soil quality (Bama 2016; Bama et al. 2013; Meena and Yadav 2015; Kumar et al. 2018).

The soil C stock worked out to be 18.63 t/ha/year in Cumbu Napier grass than by multicut fodder sorghum (17.62 t/ha) (Fig. 1.11).

Judicious management of nutrient is important for SOC sequestration. Generally, organic usage enhances the SOC pool than the inorganic fertilizers. Compton and

Boone (2000) reported that the long-term application of manures increased the SOC pool and improved the aggregation. The role of conservation tillage on increasing SOC greatly enhanced with organic manure amendments.

Smith et al. (2000) reported that application of manure to cropland enhanced the SOC pool than in pasture land. Majumder et al. (2008) observed the maximum amount of organic C in the recommended dose of fertilizer with FYM treatment due to high biomass production. Though many studies have been done by scientists on SOC, the analytical procedures are still questionable with regard to C sequestration. Bama and Latha (2017) enforced the standardization of analytical methods for C sequestration studies and explained about the role of land use and management on soil C fractions. Bama (2018) reported the analytical procedures for C sequestration studies.

For climate change mitigation, agroforestry is the good option, because of the undisturbed condition and long-time C storage in biomass. Lal (2004) observed the effect of agroforestry with *Sesbania* on the SOC pool and C sequestration rates (ranges 4–9 mg C/ha/year). He added barren land can store SOC at 20 t/ha. Among different land use, the forest has the highest potential to mitigate, followed by agroforestry, plantations, agriculture, and pasture.

The conservation practices, viz. reduced tillage, crop residue management, agronomical practices in crops, and cover cropping in plantation crops, have other benefits to improving soil properties, i.e. chemical and biological qualities, and crop productivity enhancement besides improving Cn sequestration.

The increased physical stabilization of SOC by the reduced tillage was reported by Plaza-Bonilla et al. (2010). An annual increase of 1% SOC was reported with no-tillage in Mediterranean croplands (Aguilera et al. 2013; Gogoi et al. 2018; Meena and Yadav 2014), and it is above the 0.4% target of recent initiative on sustainable soil conservation (4 per mille concept). In the semiarid region, no-tillage fixed 0.5 mg C/ha/year and recommended tillage practice observed with only 0.06 mg C/ha/year. However, contrary to that, a steady increase of sequestration may not be true because the accumulation rate may change in the long term (Alvaro-Fuentes and Paustian 2011). Reduced tillage is an acceptable practice to mitigate climate change. Even no-tillage required herbicide application to control weeds which may cause environmental pollution. The effort is required to promote no-tillage with reduced use of herbicides.

Research in tropical forests has reported that 20–80% of fine roots are colonized by AMF (arbuscular mycorrhizae fungi). The collocation to the AMF and their soil C contribution is based on one of the compounds produced by AMF, i.e. glycoprotein called glomalin. The concentration of glomalin in soil ranges from 2 to 15 mg/g of soil. The glomalin improves soil aggregation thereby protecting C from degradation in soils. Rillig (2004) reported that mycorrhizal fungi are an important part of the SOC pool in addition to C sequestration by soil aggregates stabilization. The role of AMF in mitigating climatic change has been reviewed by Staddon et al. (2002). Studies conducted with C14 labelling revealed that photosynthate is transferred from host plants to AMF fungi within hours after labelling (Johnson et al. 2002; Layek et al. 2018; Meena and Lal 2018). The AMF form root colonies with more than 80% of the plant species. It will make a symbiotic relationship with higher plant roots. Hyphae radiate out of roots and spread with the long mat. These colonies form a pathway for transfer of photosynthetic C and to the soil. Since glomalin takes decades to centuries for decomposition, it can improve C sequestration rate in soil.

Application of biochar to agriculture paved the way for storing C for a long time undistributed in the soil, and researches have reported that biochar will reduce the greenhouse gas emissions. Biochar is a biologically very tightly fixed C which is not easily degraded by the soil microbes. The C present in biochar has an aromatic form which is highly resistant to decomposition (Purakayastha et al. 2015; Meena et al. 2017b). Biochar is a highly caseous pyrolysed product of biomass. Purakayastha et al. (2015) revealed that CH_4 emission from rice soil significantly reduced with the application of cornstalk biochar. Furthermore, biochar application improved the methanotrophic bacteria rather than methanogenic which induce CH_4 emission.

Galinato et al. (2011) reported the effect of biochar on N_2O that it not only reduces the cumulative N_2O emission (52–84%) but also NO (47–67%) compared to mineral fertilizer. In India, a total of around 500 MT of residues are produced; if it is converted into biochar, about 50% of C can be captured because the soil is determined to hold more (1100 Gt) C than the atmosphere (750 Gt) and terrestrial biosphere (560 Gt). The global flux of CO_2 from soil to atmosphere is about 60 Gt of C per year due to decomposition of soil and microbial respiration. Most C in the terrestrial biosphere (86% of above-ground C) is in forest green cover; also, 73% of the soil C is in forest soil.

The mitigation potential of organic farming on three greenhouse gases given by Kotschi and Muller-Samann (2004) showed that permanent soil cover, reduced soil tillage, restriction of fallows in semiarid regions, and diversification of crop rotations including fodder production reduce the CO_2 and N_2O emissions. Use of manure and waste, recycling of municipal waste and compost, biogas slurry, reduction of fodder import, and restriction of livestock density reduce the CH_4 emission. In addition to that, restriction of nutrient input, inclusion of leguminous plants, consumption of regional products, and shift towards organic vegetarian products reduce the CO_2 and N_2O release.

1.8 New Concept for Climate Change Mitigation

The new concept, i.e. 4 per millie, was started during the Conference of Parties 21 (COP21) at Paris with an intention to increase SOC stocks by 0.4% per year as compensation for anthropogenic emission of greenhouse gases (Fig. 1.12).

According to Batjes (1996), annual GHG emission from fossil C is 8.9 gigatonnes, and global estimate of soil C stock to 2 m of soil depth is 2400 gigatonnes. If we consider our world land area to be 149 million cm2, C storage would be estimated at 161 tonnes per hectare. So 0.4% equates 0.6 tonnes of C per hectare per year to be sequestered. This 0.4% cannot be applied everywhere since soils vary in their storage capacity. Based on the research work published, SOC sequestration

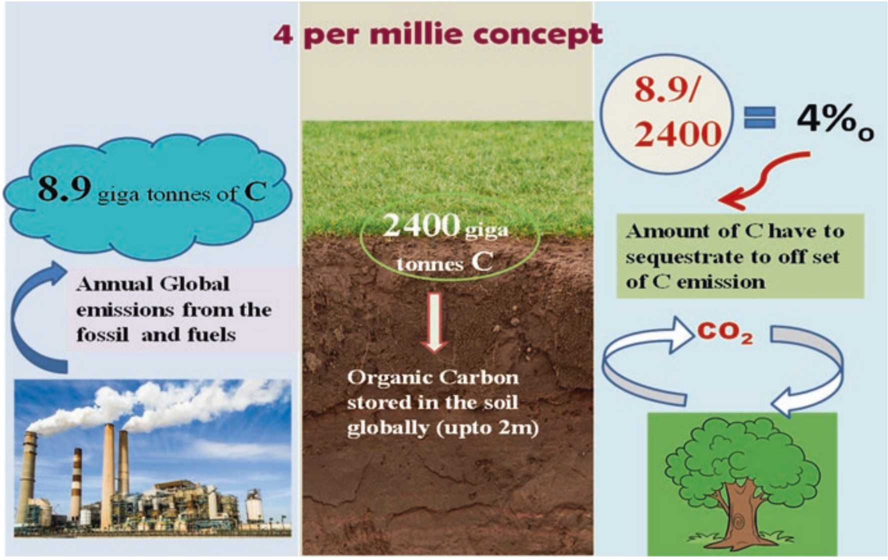

Fig. 1.12 New concept for climate change mitigation (Batjes 1996)

rate of 0.2–0.5 tonnes C per hectare is feasible with best management practices such as reduced tillage, inclusion of legumes in the crop cycle, cover crops, application of organic manures, reduction of fertilizer use, and crop residue mulching. Chen et al. (2015) reported that increasing the SOC level is possible due to improved management practices. Some researchers suggest that the soil has a limited holding capacity to store C, i.e. called C saturation. There is a hypothesis, i.e. a critical level of C and C saturation, which depends on soil texture and climatic condition (Stockmann et al. 2015; Meena et al. 2018b).

1.9 Implementation Policies for GHGs Reduction

To mitigate climate change, India has started a capacity building programme on research and development in climate resilient agriculture called National Innovations on Climate Resilient Agriculture (NICRA) which aims to train agricultural scientists in climate change adaptation strategies. The following researchable issues are to be taken up by the scientist to mitigate climate change (Pathak 2015).

Policy Issues

- Establishing an institutional mechanism for data collection and management of GHG inventory at state and national levels
- Linking all government subsidies, viz. fertilizer resistibly and other agri-inputs with GHG mitigation
- The inclusion of mitigation technologies in developmental schemes at national- and state-level plans

- Developing a C credit programme and by innovative payment mechanisms
- Enhancing research funding to do focus research on climate change mitigation through creating a separate wing in all funding agencies
- Capacity building to officials and awareness creation at the public for best management practices which mitigate climate change

Future Thrust

- Developing a feasible methodology for measuring GHG emission
- Developing low C and N emission agricultural technologies
- Methodologies for reducing GHG emission from livestock by better management of feeding practices
- Assessing mitigation co-benefits of climate change mitigation technologies
- Assessing the cultural and economic feasibility of greenhouse gas mitigation technologies

1.10 Conclusion

The soil is the key component of the agricultural production system. Hence soil health needs to be relooked in light of projected climate change for sustainable agricultural productivity. Evaluation and dissemination of climate resilient soil management strategies are required to mitigate the probable impacts of climate change on agriculture. Due to continuous climate variations, greenhouse gases are produced and in turn created global warming potential. The greenhouse gases, viz. CH_4, N_2O, and CO_2, are important sources from agriculture. The main source of CH_4 emission is from rice soils due to continuous submergence and fresh organic matter addition. N_2O is emitted to the environment by the continuous use of Nous fertilizer. The source for CO_2 is from the soil through tillage operation, land use change, and cropping system. The mitigation strategies for CH_4 from rice soil are through the adoption of water management by alternate wetting and drying practice. The N_2O emission can be reduced by less usage of N fertilizer, nitrification inhibitor, LCC-based N application, and inclusion of legume crops in the crop rotation by promoting biological N fixation and reducing the N use. The CO_2 emission from soil can be reduced by selection of crops with high C harvesting potential especially belowground C storage of high root biomass, no-tillage, organic soil cover, crop diversification, proper nutrient management by including more of organics, improving AMF count, application of biochar, etc. The new initiative started during COP(21) is also insisting the soil C storage rather than thinking the other methods to reduce the GHG emission. The mitigation options to manage the climate change are available either alone or in combination in the farmer fields needs governmental support. Policies and incentives should be evolved that would encourage the farmers to adopt mitigation options, improve soil health, and use water and energy more efficiently.

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