Emission of Greenhouse Gases from Soil: An Assessment of Agricultural Management Practices

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Abstract

Increasing concentrations of the atmospheric greenhouse gases (GHGs) are serious threats to the living beings and their niches. The rapid increase in GHGs is undoubtedly related to anthropogenic activities. Literature related to GHG emissions and mitigation approaches is widely available, but very few reviews concentrated on spatial-temporal trends of GHG emission from the agriculture sector. Agriculture is a potent contributor to GHG emissions, involving different agricultural practices followed by the farmers, which affect the rate of emission either positively or negatively. Agricultural soil management practices add excess nutrients, which disturb the natural mineral cycling leading to soil and water pollution and increase emission from soil to atmosphere, thus contributing to climate change. Research papers and reports related to GHG emission from different agricultural sectors in different parts of the world were reviewed to find the variations in emission pattern and intensities, and the factors influencing the emissions from the soil. The soil GHG emissions are directly or indirectly modified by natural as well as anthropogenic factors, like pH, soil texture, tilling, fertilizer application, mulching, irrigation, etc. The determinants taking part in the soil GHG emissions varied with region and different agricultural practices. Different mitigation approaches for GHGs from the agriculture sector were also compared for their efficacy in reducing emissions. A variety of advanced techniques developed to enhance the yield of crops were found to influence GHG emissions by direct influence on soil pH, temperature, and moisture. The conditions favorable for GHG emissions can be modified to reduce

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P. Singh et al. (eds.), *Plant Responses to Soil Pollution*,
https://doi.org/10.1007/978-981-15-4964-9_14

the emissions as the soil acts both as a reservoir and as an emitter of GHGs based on local natural and anthropogenic factors.

Keywords

Greenhouse gas · Agriculture · Soil · Impact on plants · Mitigation

14.1 Introduction

Climate change is a long-term alteration in weather conditions that include major changes in temperature, precipitation, wind patterns, etc., that occur over several decades or longer (IPCC 2014). The significant changes in weather variables may lead to large and potentially dangerous shifts in climate and weather. The Earth's average surface temperature has risen by 0.93 °C through 2016, since the start of global record in 1880 (Dahlman 2017). The ongoing rise in global mean temperature near the Earth surface is global warming. The major causes of global warming are the increasing concentrations of GHGs in the atmosphere. Water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), etc. present in the atmosphere absorb the thermal infrared radiation that is emitted and reflected by the Earth surface and reradiate back to keep the Earth warmer. Thus, the GHGs are responsible for maintaining the optimum temperature of the Earth. If GHGs do not exist, the average temperature of the Earth would have been -18 °C. Due to the presence of GHGs, there is an increase in the temperature by 34 °C (NASA 2010). The greenhouse effect is the process of trapping and reradiating the thermal infrared radiation by GHGs into the atmosphere. The current increases in GHGs due to anthropogenic activities retain more thermal infrared radiation close to the Earth surface resulting in an increase in global mean temperature and thus to global warming. GHGs and their characteristics are given in Table 14.1.

The continuous increases in the concentrations of GHGs in the atmosphere are not only implicated the global warming, but also sea level rise and reductions in carbon sequestration in terrestrial and oceanic carbon pools (IPCC 2007). GHG emissions are rising every decade, but the anthropogenic emissions were highest during 2000–2010 (IPCC 2014). In 2010, from total anthropogenic emissions, CO_2 accounted for 76%, CH_4 for 16%, N_2O for 6.2%, and 2% was contributed by fluorinated gases (IPCC 2014). Emissions from the agriculture sector also come under anthropogenic inputs. Major sources of agricultural soil pollution are applications of chemical fertilizers, pesticides, organic manure, and other inputs that are used vigorously to increase the productivity of plants. The nutrients from these inputs are not totally utilized by the plants and lost due to leaching, run off, and also emitted to the atmosphere, thus disturbing the nutrient cycle. These practices affect the emission of GHGs from soil. This review paper focuses on the current knowledge of GHG emissions from the agricultural sector, the local environmental and anthropogenic factors governing the emissions, and the effect on agriculture and the available strategies to reduce the concentrations of GHGs in the atmosphere.

Table 14.1 Greenhouse gases and their characteristics

Greenhouse gases	Concentration	Concentration (2005) (WDCGG)	Trend (per year, 2005–2016) (WDCGG)	Global warming potential (USEPA 2017)	Lifetime (years) (USEPA 2017)
Carbon dioxide (CO_2)	403.3 ppm[a]	379.2 ppm	2.1 ppm	1	Variable
Methane (CH_4)	1853 ppb[a]	1785 ppb	6.15 ppb	25	8–12
Nitrous oxide (N_2O)	328.9 ppb[a]	319.1 ppb	0.9 ppb	298	>100–120
Ozone (O_3)	40.7 ppb[b]	–	–	2000	Short
Chlorofluorocarbons (CFCs)	537 ppt[c]	–	–	10,600	>100
Hydrofluorocarbons (HFCs)	35 ppt[c]	–	–	Up to 14,800	Up to 270
Perfluorocarbons (PFCs)	20 ppt[c]	–	–	7390–12,200	2600–50,000
Sulfur hexafluoride (SF_6)	8.6 ppt[c]	–	–	22,800	3200

[a]WDCGG (2016)
[b]ESRL GMD (2016)
[c]CDIAC (2016)

14.2 Methodology

A literature review was performed by using world wide web for related keywords such as greenhouse gas, agriculture, agricultural practices, soil emission, factors affecting GHG emission, effects of GHGs on agriculture, GHG emission mitigation etc., on Google Scholar and PubMed. Based on the related information, 250 eligible papers relevant to the topic were selected for further consideration. For analysis of the concentration and emission trend of GHGs, data from IPCC, NASA, ESRL (Earth System Research laboratory), and WDCGG (World Data Centre for Greenhouse Gases) were downloaded from respective websites. Relevant peer-reviewed papers were also extracted from the cited reference of most important papers in this field. Relevant information observed from those studies such as different agricultural practices influencing the emission of GHGs, soil conditions modifying GHG emissions, the contribution of agriculture in total GHGs emissions, and mitigation strategies in controlling GHG emissions were briefly explored. More emphasis was given to studies in developing countries. The data of WDCGG (2016) for the time period of 2005–2016 were used for the time series analysis of CO_2, CH_4, and N_2O using the Theil-Sen approach in R-statistical software.

14.3 Greenhouse Gas Emissions

Natural sources of GHGs are decomposition, enteric fermentation in ruminants, anaerobic respiration in wetlands, denitrification, volcanic eruptions, etc. GHGs emitted from the natural sources are mainly CO_2, CH_4, and N_2O. Major anthropogenic sources of GHGs include energy production through fossil fuel burning like coal, petrol etc., biomass burning, waste decomposition, land-use change, industries, leakage during oil and gas exportation and transportation, leakage from air conditioners and refrigerators, cleaning of electronic components, production of plastic foams, propellants, and sprays, etc. (IPCC 2014). Anthropogenic sources contributing to global GHGs are given in Table 14.2.

Burning of fossil fuels is one of the major contributors in elevating the concentrations of GHGs and is involved in almost all the processes related to energy generation, electricity, industry, agriculture, transportation, etc. 9.4 and 9.6 billion metric tons of CO_2 were emitted globally from fossils fuel burnt during 2011 and 2012, respectively (ESRL GMD 2014). Emission with this rate is estimated to increase the CO_2 concentration by 11.5% over a period of 10 years. In 2012, Asia contributed to 46% in global GHG emissions and it has reached 14.5 Gt CO_2-e (CO_2-e is the concentration of CO_2 that would cause the same radiative forcing as a given mixture of CO_2 and other forcing components (IPCC 2014; US EIA 2016)). In Asia, GHG emissions are maximally contributed by energy production (48%) followed by agriculture (18%), industry (11%), residential (9%), transportation (9%), and waste (5%) (Marcotullio et al. 2012). According to a report of INCCA (2010), energy sector including electricity (37.8%) and transport (7.5%) produced higher CO_2-e whereas agriculture contributed to 17.6% of total emission in India

Table 14.2 Global anthropogenic emission of GHGs (IPCC 2014)

Sources	Emission (%)
Electricity and heat production (burning of fuels)	25
Industries (burning of fuels, chemical, metallurgical, and mineral transformation processes)	21
Agriculture, forestry, and other land use (cultivation of crops and livestock and deforestation)	24
Transportation (fossil fuel burning for all kinds of transport)	14
Buildings	6
Others	10

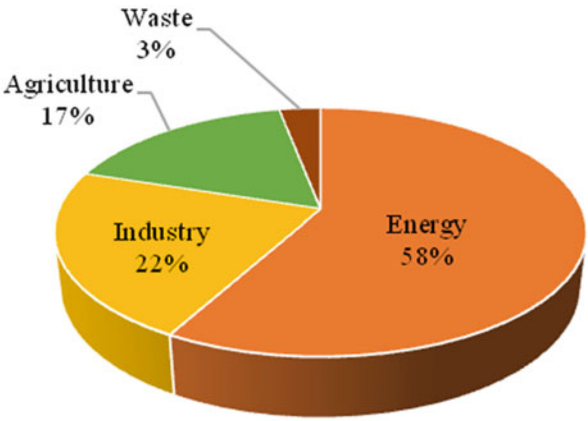

Fig. 14.1 Net CO_2 equivalent emission in India during 2007 (INCCA 2010)

(Fig. 14.1). CFCs (chlorofluorocarbons), HFCs (hydro-fluorocarbons) and PFCs (per-fluorocarbons) having very high global warming potential and lifespan are emitted only by human activities. CFCs are non-toxic, inert, and harmless gases in the lower atmosphere, but break down O_3 molecules in the stratosphere and thus contribute to O_3 depletion. The concentrations of CFCs decrease in response to the Montreal protocol.

14.4 Recent Temporal Trend of Major GHGs

Recent temporal variations in the CO_2 concentration showed a linear significant increase of 2.1 (CI, 2.01–2.2) ppm with distinct seasonal variations, whereas CH_4 and N_2O showed linear increases of 6.1 (CI, 5.74–6.62) and 0.9 (CI, 0.89–0.9) ppb per year, respectively (Table 14.1 and Fig. 14.2). There are a clear and prominent pattern of variations in CO_2 and CH_4 concentrations during different months with least values in July, August, and September.

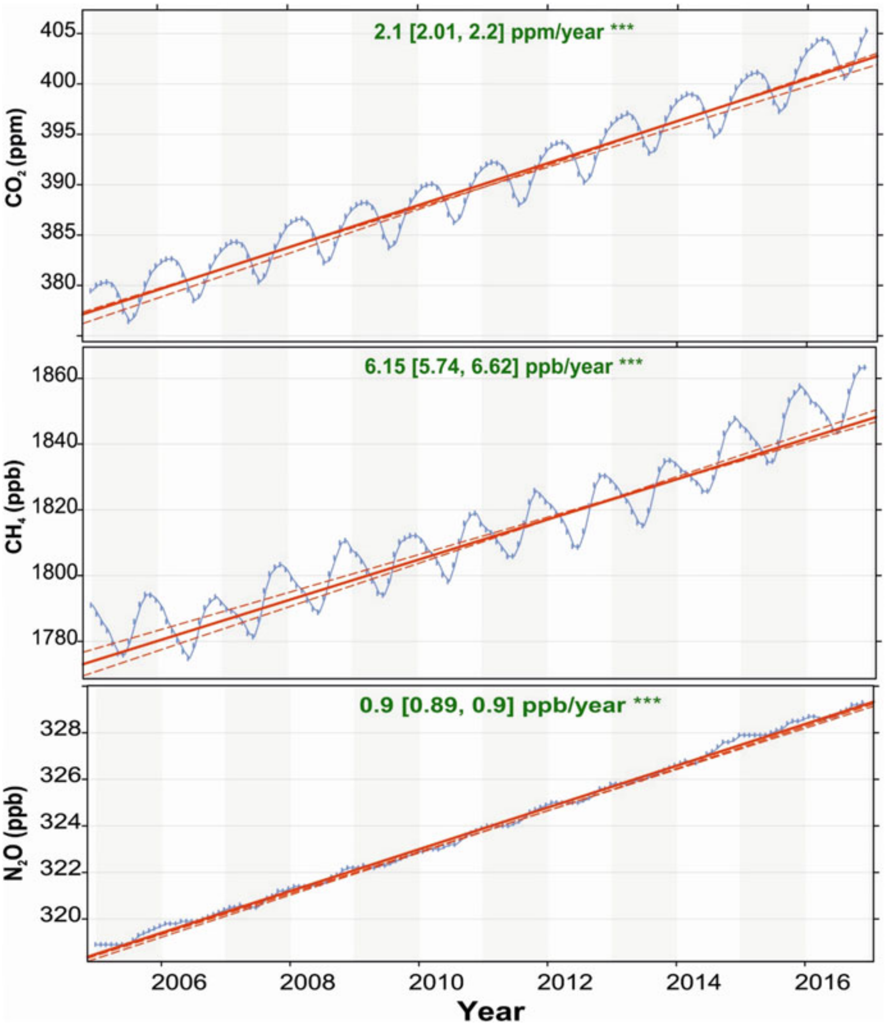

Fig. 14.2 Temporal trends of increase in CO_2, CH_4, and N_2O during 2005–2016

14.5 Greenhouse Gas Emission from Agriculture

Agriculture has occupied 179.7 M ha land in India and 1.5 billion ha globally (FAO 2003). Due to population pressure, the requirement for agricultural land continues to increase to fulfill the increasing demand for food. The contribution of agriculture in GHG emissions is increasing. Land-use, land cover change, and agricultural practices like tilling, fertilizer application, and mulching contributed about 24% (12 Gt CO_2-e) of total GHG emissions globally in 2010 (IPCC 2014). According to Scialabba and Müller-Lindenlauf (2010), global food production contributed almost one-third of total anthropogenic GHG emissions. In the United States, 9% contribution in GHGs was estimated from agriculture (USEPA 2016). In India, emission from agriculture is 334.41 million tons of CO_2 equivalent (INCCA 2010).

GHG emission from soil is due to microbial activity, root respiration, chemical decomposition processes, litter decomposition, heterotrophic respiration by soil fauna, oxidation of soil organic matter etc. The disintegration of carbon-based organic substrates emits CO_2. Root respiration utilizes intercellular and intracellular substrate molecules. The soil may act as a sink or source for GHGs depending upon the physicochemical properties of the soil and the local environment (Muñoz et al. 2010). The aerobic condition leads to the emission of CO_2, whereas anaerobic condition leads to CH_4 emission. The decomposition process also plays a major role in the carbon cycle and the process emits a significant amount of CO_2 and CH_4 (da Cunha-Santino et al. 2016). Decomposers break down organic materials in the plant and animal residues and the organic carbon present in organic materials gets converted into CO_2. In the tropical climate zone, CO_2 and CH_4 emissions are 14 tons of C ha^{-1} $year^{-1}$ and 7.0 kg of C ha^{-1} $year^{-1}$, respectively, from drained croplands (IPCC 2014). Rice cultivation is a potential anthropogenic source of GHG emissions. Developing countries are reported to contribute about 94% GHG emissions globally from rice cultivation during 2000–2010 and contribution of Asia was estimated to be about 90% (Tubiello et al. 2013).

CO_2 is although cycled in huge amounts but emitted in less amounts comparatively. It is emitted by deforestation, land-use change, fossil fuel burning, respiration, etc. Reay and Grace (2007) found that autotrophic respiration emits 60 Pg C $year^{-1}$ to the atmosphere and about the same amount is emitted by heterotrophic respiration. Water-filled pore space (WFPS) also emits a considerable amount of CO_2. In grassland soil, 20 to 40% WFPS emits high CO_2 (Schaufler et al. 2010).

Anaerobic respiration is an important source of CH_4 emission from soil. Wetlands are the major site of CH_4 emission, although they occupy a little global surface area. The rate of CH_4 emission has more than doubled over the last 25 years due to human activities (IPCC 2007). It is estimated that rice fields contribute about 11% of the total CH_4 emission globally (IPCC 2014). In 2007, 3327 thousand tons of CH_4 emission was reported from rice field, which contributed 24% of total emission from the agricultural sector in India (INCCA 2010). The live-stock management contributes maximally to total methane (73%) emission from agricultural sector (INCCA 2010) (Fig. 14.3).

In plants, methane is emitted through aerenchyma and micropores located in the leaves. As plants develop during their growing cycle, aerenchyma contribution is more than 90% in CH_4 diffusion to the atmosphere. While ebullition and diffusion through flooded water are less significant but ebullition provides major contribution during early stages (Le Mer and Roger 2001; Gupta et al. 2016). The diffusion rate is higher in the air than water so gas exchange through diffusion is very slow under waterlogged conditions. Bouwman (1990) reported that through aerenchyma, CH_4 diffusion varies on a daily basis due to the effects of environmental factors on the

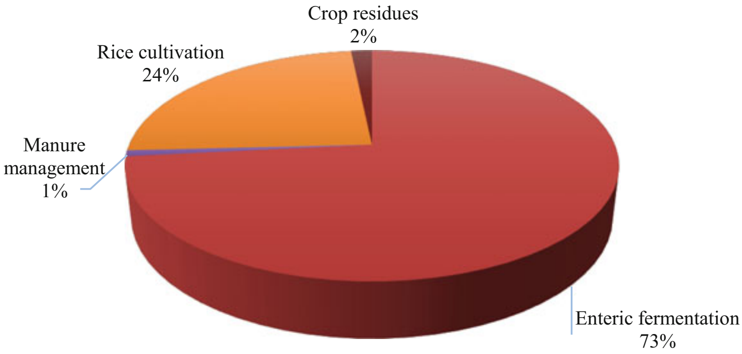

Fig. 14.3 Methane emission from agriculture sector in India during 2007 (INCCA 2010)

rate of photosynthesis/respiration. Biochemical reactions involved in methanogenesis are following:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

$$CH_3COOH \rightarrow CH_4 + CO_2$$

This involves various substrates mainly acetic acid, CO_2, and other organic compounds, involving a number of coenzymes and cofactors.

Due to the highest global warming potential among the three major GHGs, N_2O has a high impact on the environment despite being in very low concentration. The agriculture system potentially emits N_2O due to fertilizer application and denitrification processes. The denitrification process is the conversion of NO_3^- to N_2, which includes many intermediates as shown below. N_2O is one of the intermediates that escape in the atmosphere. In some cases, NO_3^- is converted to ammonia through the process of dissimilatory nitrate reduction to ammonium (DNRA) and N_2O is released into the environment. Agricultural activities contribute about 77% of total N_2O emission in U.S. (USEPA 2016). It is emitted under both aerobic and anaerobic conditions. Urea and ammonium sulfate are major fertilizers used in rice and other crop fields and are primary sources for N_2O emission.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2.$$

DNRA:

$$NO_3^- + 4H_2 + 2H^+ \rightarrow \overset{N_2O \uparrow}{NH_4^+} + 3H_2O.$$

14.6 Factors Affecting GHG Emissions from Soil

Different agricultural practices affect the pool of soil organic carbon and in turn, affect the emission of GHGs. Not only the management practices during agriculture but also the local environmental factors influence the emission of GHGs from the soil (Fig. 14.4). Effects of different factors on emissions of GHGs are described below.

14.6.1 Agricultural Practices Affecting GHG Emissions

Different agricultural practices that are utilized by the farmers to enhance the productivity like tilling, use of fertilizers, etc. may modify the GHG emissions significantly. Roles of agricultural practices in modifying GHG emissions are discussed below and the results are summarized in Table 14.3.

14.6.1.1 Fertilizer Application

To increase the productivity of crops, the use of fertilizers has risen dramatically. Both organic and inorganic chemical fertilizers affect GHG emissions but organic fertilizers having carbon emit comparatively high CH_4. Mulching and organic manure application increase CH_4 emission (Ma et al. 2007). Emission of N_2O from soil is largely dependent upon nitrogen availability in the soil (Pandey et al. 2012; Pathak et al. 2010). Application of nitrogen fertilizers greatly enhanced N_2O flux from the rice-wheat system (Pandey et al. 2012) and fluxes of both N_2O and CO_2 from sugarcane field (Pandey and Agrawal 2015). Nitrous oxide fluxes increased linearly with the nitrogenous fertilizer application rate (Gregorich et al. 2005), which may be due to increase in the substrate for microbes (Pandey et al. 2012). Organic manure amendment sites showed higher GHG fluxes (Thangarajan et al. 2013). Application of nitrogen fertilizer increases the plant growth and the carbon supply to methanogens, which leads to more production and transport of CH_4 to the atmosphere. According to a report of INCCA (2010), 0.115 million tons of CH_4 and 0.07 thousand tons of N_2O were emitted in India due to manure addition mainly using dung cakes.

Chemical fertilizers like urea increase the emission of CH_4 by increasing the plant biomass and productivity thus providing more organic substrates to methanogens for biomass decomposition and root exudation (Jia et al. 2001). In contrast, nitrogen fertilizer application was reported to decrease CH_4 emission by 35–50% in paddy fields (Yao et al. 2012). This may be due to rhizospheric development, which may have improved oxygen transport and increment in methanotrophic activity (Bodelier et al. 2000). Chemical fertilizers affect the microbial community leading to low or high emission. Urea produces CO_2 after conversion into bicarbonate (HCO_3^-) in the presence of water. The mode of fertilizer application and the type of fertilizer have significant effects on CH_4 and N_2O emission (Yao et al. 2017). When anhydrous ammonia is injected into the soil in the gaseous form, it produces a highly alkaline zone with a high ammonium concentration, which leads to high N_2O emission

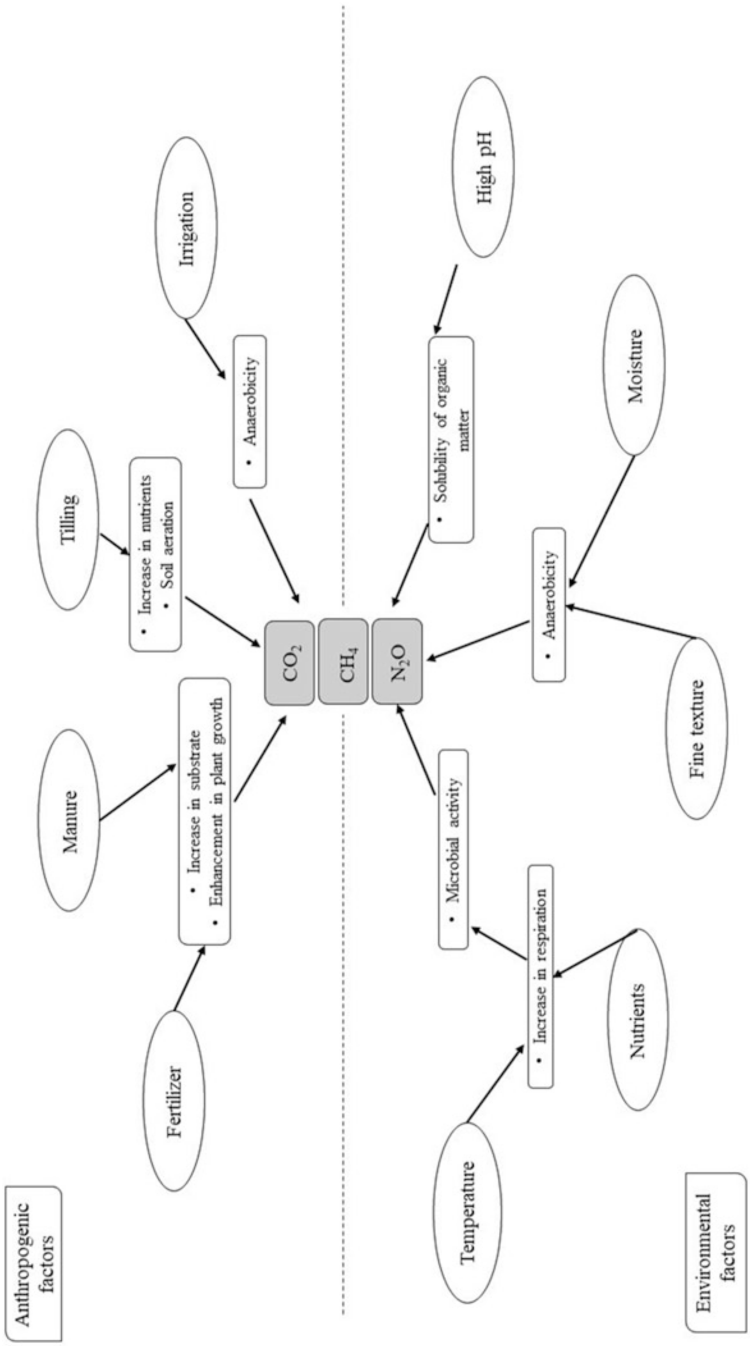

Fig. 14.4 Factors influencing greenhouse gas emissions from agricultural land

Table 14.3 GHG emissions under different agricultural practices

S. no.	Agricultural practices	Location of sites	Study period	GHG emissions				Inferences	References
				Practices	CO_2	CH_4	N_2O		
1.	Crop rotation	Thailand	2010–2011	RF RR RC RS	43,260 kg ha^{-1} 89,810 63,840 82,120	185.84 893.49 198.87 165.72	5.77 1.54 7.77 8.93	Corn and sweet sorghum as alternative crops to rice for emission reduction	Cha-un et al. (2017)
2.	Fertilizer application	China	2013–2014	PNN PBP GNN GBP GDP	– – – – –	83.6 kg ha^{-1} 79.9 21.8 13.0 13.7	0.14 1.91 0.14 5.09 2.71	Deep placement of urea in underground cover production system reduced emission without affecting yield	Yao et al. (2017)
3.	Fertilizer application	China	2006	C NP NK NPK FOM ROM	– – – – – –	622 kg ha^{-1} year^{-1} 685 650 794 1174 1081	1.15 2.46 2.97 1.93 4.11 3.37	Inorganic fertilizer and long-term fertilizer application increase GHG emission	Shang et al. (2011)

(continued)

Table 14.3 (continued)

S. no.	Agricultural practices	Location of sites	Study period	GHG emissions Practices	CO_2	CH_4	N_2O	Inferences	References
4.	K fertilizer application	India	2002	C K_{30} K_{60} K_{120}	– – – –	125.34 kg ha^{-1} 63.81 82.03 40.95	– – – –	K application significantly reduced CH_4 emission and enhance rain fed rice yield	Babu et al. (2006)
5.	N fertilizer, residue and tillage	India	2013–2015	CT-R + 100N CT + R + 100N CT + R + 75N + GS ZT-R + 100N ZT + R + 100N ZT + R + 75N + GS	321 kg ha^{-1} 318 301 289 280 266	380 g ha^{-1} 360 330 440 420 390	– – – – – –	GWP reduced significantly under no-tillage, surface residue application and real-time N management through Greenseeker	Nath et al. (2017)
6.	Urea application	India	2004–2005	T1 T2 T3 T4	1092 kg ha^{-1} 1483 1348 1431	31.0 35.6 32.1 34.1	0.285 0.788 0.665 0.735	Leaf color chart-based urea application reduced global warming potential of rice cultivation under rice-wheat system	Bhatia et al. (2012)

7.	Irrigation	Denmark	2014		GWP		Islam et al. (2018)
				CF SM LM SE + SM SE + LM LE + SM LE + LM	11,598 mg g soil^{-1} 6385 6777 4546 3250 1638 1443	Early season drainage in rice reduced emissions	
8.	Irrigation	Italy	2012–2013	WFL DFL DIR	9.65 CO_2 eq ha^{-1} year^{-1} 4.26 1.62	Dry seeding treatment and intermittent irrigation reduced emissions	Peyron et al. (2016)

RF fallow-rice, *RR* rice–rice, *RC* corn-rice, and *RS* sweet sorghum-rice; *PNN* no N fertilization in the traditional paddy rice production system, *PBP* broadcast placement of urea at a common rate of 150 kg N ha^{-1} in the traditional paddy rice production system, *GNN* no N fertilization in the ground cover rice production system, *GBP* broadcast placement of urea at a common rate of 150 kg N ha^{-1} in the ground cover rice production system, *GDP* deep-point placement of urea at a common rate of 150 kg N ha^{-1} in the ground cover rice production system; *NP* nitrogen and phosphorus fertilizer, *NK* nitrogen and potassium fertilizer, *NPK* balanced inorganic fertilizer, *FOM and ROM* combined inorganic/organic fertilizers at full and reduced rate respectively and *C* no fertilizer application; *C* control, *K* potassium application in kg ha^{-1}, values indicate the amount of potassium fertilizer; *CT* conventional tillage, *ZT* zero tillage; *R* residue application, *100N* 100% required N, *75N* 75% N, *GS* additional N based on need according to Greenseeker™, positive and negative signs showing presence and absence of particulars; *T1* unfertilized control, *T2* conventional urea application (120 kg N ha^{-1}), *T2* leaf chart color (LCC) based urea application (30 kg N ha^{-1} at LCC $\leq$ 4, no basal N), *T4* LCC based urea application (30 kg N ha^{-1} at LCC $\leq$ 5, no basal N); *CF* continuous flooding, *SM* short mid-season drainage, *LM* long mid-season drainage, *SE* short early-season drainage, *LE* long early-season drainage, *WFL* water seeding and continuous flooding, *DFL* dry seeding with flooding at tillering stage, and *DIR* dry seeding with intermittent irrigation

(Bouwman 1996). KNO_3 application in soil emits three to eight times higher N_2O than ammoniacal fertilizer (Abbasi and Adams 2000). When the fertilizer is applied in dry weather, then the emission of N_2O is small compared to humid conditions (Zhang and Han 2008). Ma et al. (2007) observed that CH_4 emission is enhanced when a low-nitrogen fertilizer is applied, but when high rates of fertilizer are applied, emission decreased. Deep placement of urea decreased CH_4 and N_2O emission in the rice field and also increased the rice yield (Yao et al. 2017).

14.6.1.2 Use of Pesticides

Excessive and improper use of pesticides can be a major environmental hazard and also a human health concern. Pesticide application usually decreases CH_4 emission. Mohanty et al. (2001) reported 20% decrease in CH_4 emission when herbicide Butachlor was applied in direct seeded flooded rice field. Glyphosate and Propanil inhibit N_2O production in laboratory condition under organic amendment (Kyaw and Toyota 2007). Das et al. (2011) reported that when two herbicides Bensulfuron methyl and Pretilachlor were applied separately, CH_4 and N_2O emissions decreased, but when applied in combination, the emissions increased. The population of methanogenic and methanotrophic bacteria is influenced significantly by herbicides (Das et al. 2011).

14.6.1.3 Soil Cover

Plant residues are used as a soil cover to reduce erosion, maintain soil moisture, and increase soil quality, but they contribute to GHG emissions. Plant residues get colonized by decomposers that produce simpler, low molecular weight compounds from complex compounds such as cellulose, hemicellulose, lignin, proteins, etc. which may produce or consume GHGs. According to Muhammad et al. (2011) plant residues like sugarcane trash, maize and sorghum straw, cotton residues, and lucerne increased the cumulative N_2O emission by about a factor of 3. In the crop rotation system, incorporation of maize and wheat straw increases N_2O emission by increasing the temperature of soil due to its heat retention capacity (Liu et al. 2011). Baggs et al. (2000) observed increased N_2O emission for about 2 weeks after the incorporation of crop residues. Biochemical composition of residue also affects the emission due to the availability of nutrients (Gomes et al. 2009). N_2O emission is higher where soil receives residues with a low C/N ratio (Toma and Hatano 2007). Gupta et al. (2016) have also reported that a high C/N ratio in the rice residue reduces N_2O emission by 12.8% and 11.1% in 2 consecutive years. Further high C/N ratio in residue increases the rate of immobilization, thus lowering the substrate availability for nitrification and denitrification. Kallenbach et al. (2010) reported that nonlegume cover crops like winter cereals reduced N_2O emission possibly due to their deep roots taking up N more efficiently than legumes.

14.6.1.4 Tillage

Tillage breaks down soil aggregates, help in mixing soil and organic particles, and improve infiltration and water-holding capacity of the soil. Tilling of the crop field influences the emission of GHGs due to disturbances in the soil, addition of residues in soil, and also decomposition of soil organic matter leading to changes in the properties of soil. According to Nath et al. (2017), higher emission of CO_2 occurs due to weak stabilization as tilling causes oxidation of carbon. Gaseous transport is affected under no tilling condition due to soil compactness and low mobility of gases along the soil profile. Almaraz et al. (2009) reported that soil with no tilling acts as a sink for N_2O due to consumption in soil layer. In contrast, Liu et al. (2006) and Nath et al. (2017) reported greater N_2O emission under no-tillage condition compared to conventional tilling. Gupta et al. (2016) found that N_2O emission was 8–11% higher under zero tillage in wheat-cropped soil than conventional tillage. Tilling causes aeration of soil and denitrifiers are not able to produce N_2O under aerobic conditions. CH_4 and N_2O emissions are reduced, while CO_2 emission increased when tillage frequency is reduced in rice-wheat cropping system (Pandey et al. 2012). Conservation tillage and no-tillage lead to an increase in the carbon storage of soil. Minimum tillage resulted in highest N_2O emission after surface application of the nitrogen fertilizer (Bouwman 1996).

14.6.1.5 Water Management

Flooding or water-logging conditions lead to CH_4 emission. Rice is grown usually under submerged conditions. Nishiwaki et al. (2015) reported that highest emission of CH_4 occurs from the continuous-flooding treatment and small emission from low-water-level treatment. It was also reported that GHG fluxes were larger from rice growing fields than bare areas. Reduced timing for draining may decrease CH_4 emission. Rice field acted as a CO_2 sink and was not affected by variation in water treatments, while N_2O fluxes did not show any specific pattern (Nishiwaki et al. 2015). Water management practices that limit CH_4 production, generally enhance N_2O production (Zou et al. 2005). Intermittent irrigation in paddy fields emits less CH_4 compared to permanent flooding conditions (Pathak et al. 2010; Peyron et al. 2016). Under wetting and drying conditions of rice-wheat system, CH_4 emission was reduced under drying period as aerobic conditions prevailed at that time leading to higher methanotrophic compared to methanogenic activity but CH_4 flux was higher under wet conditions (Gupta et al. 2016).

14.6.1.6 Crop Commodity

Vegetable cultivation is the major contributor to GHG emissions and the emission is largely dependent on use of fertilizers, mulching, etc. (Tongwane et al. 2016). Among the cereal crops, maize and wheat emit significantly higher GHGs in South Africa followed by sugarcane (Tongwane et al. 2016). Among the legumes and oilseeds, soybeans, sunflower, and ground nut are reported as the highest emitter of GHGs (Tongwane et al. 2016). Similarly, potato, cabbage, and tomato from the vegetable group contribute significantly to GHG emissions. Jain et al. (2016) observed no particular variations in CO_2 emission in different crops, but reported higher CO_2 emission from *rabi* crops due to temperature variations. The emission of N_2O was more from wheat and maize than rice crop that might be due to a high rate of aerobic decomposition. On application of N fertilizer, N_2O emission was found to be the highest in the case of pulses as compared to cereals and oilseeds (Jain et al.

2016). Metanalysis done by Linquist et al. (2012) also showed that wheat cropping emitted higher N_2O than rice, and maize led to highest emission among them. CH_4 emission was higher from rice field and wheat and maize acted sinks for CH_4. Even the crop rotation helped in reducing the emission as lower fertilizer application was done (Gao et al. 2014). Pandey and Agrawal (2015) compared the emission between pigeon pea and sugarcane and found that pigeon pea emitted higher CO_2 than sugarcane, while a little difference was observed in N_2O emission and both the crops acted as sinks for CH_4. Leguminous crops emit less N_2O as no N fertilizer application is needed and also help in carbon sequestration (Jensen et al. 2012). Crop rotation with corn and soybean is reported to reduce N_2O emission and increase in the yield compared to continuous corn or soybean cropping systems (Behnke et al. 2018).

14.6.2 Environmental Factors Affecting GHG Emissions from the Soil

The GHGs from the soil are produced as a result of microbial processes and hence largely depend on temperature, water availability, pH, nutrient availability, soil type, texture, etc.

14.6.2.1 Soil Temperature

Microbial metabolism usually increases with increasing temperature and thus high respiration leads to high CO_2 emission and decreases in the O_2 concentration, which may produce anaerobic conditions leading to N_2O and CH_4 production. Tang et al. (2003) reported that N_2O and CO_2 emissions increase exponentially with temperature. The temperature response of gas emissions from soil is expressed as the temperature sensitivity factor (Q_{10} value). It is the rate of change in a chemical or biological system with a temperature change of 10 °C (Berglund et al. 2010) and with soil depth this tends to increase (Tang et al. 2003). Dalal and Allen (2008) estimated a Q_{10} value of approximately 4 for CH_4 emission. Wu et al. (2010) reported increase in CO_2 emission from 5 to 15 °C temperature but emission got reduced significantly when it is changed to −10 °C, suggesting that the CH_4 oxidation rate is greatly influenced by warmer temperature. N_2O emission increased exponentially with increasing temperature from 0 to 50 °C (Liu et al. 2011). These reports show that temperature has a significant effect on the fluxes of GHGs and mostly they are positively correlated. Due to an increase in temperature, soil respiration and denitrification processes increase leading to the enhanced flux of GHGs.

14.6.2.2 Soil Moisture

Moisture content of the soil is an important controlling factor of the microbial activity and thus influencing emission of GHGs. Moisture content is usually associated with the soil type. CH_4 emission increases with increasing soil humidity as strict anaerobic condition is required for the production of CH_4 (Gao et al. 2014). Emission is stimulated after wetting of a dry land and drying and wetting cycles of the soil leading to rapid emission of GHGs due to the mineralization of soil organic matter (Birch Effect) (Birch 1958) leading to increase in microbial metabolism due to availability of easily decomposing material (Ludwig et al. 2001). Sponseller (2007) reported that emission increases suddenly after rainfall and then declines after a few days to the background level.

Emission of N_2O is also significantly affected by the moisture content of the soil. As the moisture content increases, N_2O emission also increases (Baggs et al. 2000) and emission greatly enhances after rainfall and irrigation (Liu et al. 2006). Water-filled pore spaces (WFPS) play an important role in emission as they affect denitrification and respiration processes. Gao et al. (2014) observed that soil with 60% water-filled pore spaces showed optimum emission, while the least emission was reported at less than 30% WFPS. This may be due to the reason that high water-filled pore spaces provide less space for air inside the soil thus maintaining the anaerobic conditions favorable for denitrification.

14.6.2.3 Soil Type

Fine-textured soil like clayey shows more N_2O emission than coarse-textured like sandy soil (Stevens and Laughlin 1998). Similar findings were reported by Tan et al. (2009) that soil management practices in clay loam soil and rain-enhanced N_2O emission by four times than in sandy loam. This is because fine-textured soil provides more anaerobic sites in micropores for denitrifiers than in sandy soil. CO_2 emission is also higher in fine-textured soil (Dilustro et al. 2005).

14.6.2.4 pH

Soil pH affects microbial activity by affecting their enzymatic activities. Denitrification process is slowed down under low pH as the enzyme nitrous oxide reductase is inhibited by low pH and in presence of O_2 (Chapuis-Lardy et al. 2007). Similarly, CO_2 emission is decreased under low pH. Čuhel et al. (2010) reported that N_2O emission is highest at neutral and alkaline soil pH. CH_4 production by methanogens is very sensitive to pH and their activities are optimum under near neutral or slightly alkaline pH (Wang et al. 1993; Garcia et al. 2000). A slight change in pH changes the rate of CH_4 emission (Wang et al. 1993). Some of the methanogenic species can grow even at a lower pH of 5.8 (Garcia et al. 2000). Ye et al. (2012) have reported that an increase in pH enhances the emission of CO_2 and CH_4. This may be due to an increase in the fermentation process and availability of methanogenic substrates. The solubility of organic matter also increases with an increase in pH in wetland soil and as a result, the microbes produce more CO_2 (Grybos et al. 2009).

14.6.2.5 Nutrients

When the soil is carbon-rich, relatively higher N_2O emission occurs (Brentrup et al. 2000). Higher carbon in the soil induces the microbial activity and the available oxygen in the soil is also consumed due to active growth of the microbes, thus providing an anaerobic condition to the microbes and organic carbon for the process of denitrification. The relation of organic matter availability and N_2O emission depends upon the anaerobic conditions led by the microbes (Stevens and Laughlin

1998). C/N ratio is also an important factor in determining the process of nitrification and denitrification as it decides the balance between immobilization and mineralization. Baggs et al. (2000) reported that N_2O emission is significantly less when the soil was provided with straw having a high C/N ratio due to the immobilization process and higher N_2O emission occurred when no straw or straw with low C/N ratio was applied.

14.6.2.6 Salinity

Salinity is emerging as a major problem for agriculture. Mainly the arid and semi-arid regions are affected by salinity due to low rainfall. According to the report of FAO (http://www.fao.org/soils-portal/soil-management/management-of-some-problem-soils/salt-affected-soils/more-information-on-salt-affected-soils/en/), about 397 and 434 M ha of the land area in the world are affected by salinity and sodicity, respectively. Salinity is an important factor that limits plant growth and yield due to the limitation of organic matter present, high salt concentration in the soil and low osmotic potential of the salt solution. High salt concentrations in the soil also alter the physico-chemical and biological properties of the soil. Saline soils are characterized by >4 dSm^{-1} electrical conductivity, >15 exchangeable sodium percentage (ESP) or more than 13 sodium absorption ratio (SAR). Areas affected by salinity are expected to increase due to natural and anthropogenic activities such as irregular irrigation practices, weathering of salt containing rocks and precipitation.

Emissions of GHG are also influenced by salinity. There are contradictory opinions about the salinity and microbial activity. Pathak and Rao (1998) observed reduced microbial activity when the electrical conductance of the soil was high enough to cause osmotic stress. In contrast, Nelson et al. (1996) reported high microbial activity at high SAR. Salinity negatively affects GHG emissions in paddy field (Tang et al. 2016). Emission of methane is higher from fresh water habitats than from saline wetlands (Poffenbarger et al. 2011). The salt marsh present near the sea receives a great amount of sulfate and sulfate-reducing microbes, which decompose organic matter anaerobically grow abundantly. Methanogenesis is reduced due to sulfate reduction (Wang et al. 1996). Salt marshes act as sinks for atmospheric CO_2 and CH_4 (Weston et al. 2014).

14.7 Impacts of Enhanced Greenhouse Gas Emissions on Agriculture

Agriculture is affected by an increase in temperature, changes in precipitation pattern, flooding of coastal areas, soil salinization (IPCC 2014), and many indirect effects on crops such as loss of pollinators, pest infestations, etc. (Bale et al. 2002). Agricultural crops are affected by heat stress by various ways like the rate of photosynthesis is reduced, pollen production and viability are decreased, the rate of seed abortion is increased and reductions in grain weight and number occurred (Prasad et al. 2006). Bale et al. (2002) have reported that higher temperature during winters increases the rate of herbivory and winter survival of pests. Different crops responded differently to varying temperature and have different optimum temperatures (Sánchez et al. 2014). Schlenker and Roberts (2009) reported a reduction in yield of rainfed crops at 30 °C air temperature in the United States. High temperature also causes evaporation from soil and water leading to loss of crop water. Due to evaporation of water from the soil, salinity also increases in the soil. Lobell et al. (2011) estimated the reduction in maize yield by 1% for each 1 °C increase above a base temperature of 30 °C in the sub-Saharan African region. Likewise, in India annual loss of wheat crop is estimated to be about six million tons for each 1 °C rise in mean temperature (Kang and Banga 2013). The high temperature is reported to damage the reproductive stages in cereals, millets, oilseeds, and pulses (Prasad et al. 2017).

Increasing temperature is reported to increase the biological invasion that competes for nutrients and space and thus negatively affects the diversity of native species and crop plants (Fuhrer 2003). An increase in the CO_2 concentration increases the growth of C_4 weeds that affect the growth of C_3 crops (Fuhrer 2003). Ziska (2000) reported that the presence of weeds neutralizes the positive effect of enhanced CO_2 on soybeans. Weed biomass is reported to increase under elevated CO_2 level by Ziska (2000).

The tropospheric ozone (O_3) concentration increases with an increase in the temperature especially when the temperature reaches above 32 °C. Tropospheric O_3 is known to adversely affect the rate of photosynthesis, plant growth, reproduction and yield throughout the world (Tiwari and Agrawal 2018).

Increases in CO_2 have significant effects on plant growth, leaf area, and yield (Mishra and Agrawal 2014). CO_2 enrichment also affects the nutritional quality of the crop plants. Myers et al. (2014) observed reductions of 7–15% in protein content in rice, wheat, barley, and potato tubers, but very little change in C_3 legumes and C_4 crops. Jena et al. (2018) found that CO_2 concentration at 490 ± 30 ppm reduced the grain yield by 10–13% in high yielding rice cultivar although the biomass increased by 27–29%. Grain quality and nutrient allocation were also negatively affected under elevated CO_2, whereas the low yielding cultivar of rice showed positive effects (Jena et al. 2018). Nutrient requirements of plants are increased under the elevated CO_2 level (Jena et al. 2018), so excess use of fertilizers will occur. Also, the higher CO_2 level increased the K uptake from soil but translocation of K toward storage was found to be reduced by Jena et al. (2018). Increasing the CO_2 concentration will increase the growth of both wanted and unwanted species. Meta-analysis study of Liu et al. (2018) observed that elevated CO_2 increases the flux of CO_2, CH_4, and N_2O by increasing the C and N pools in soil. High atmospheric CO_2 increased the flux of CO_2 by 24%, CH_4 by 34% in rice fields, and 12% from wetlands, while N_2O flux did not change significantly.

14.8 GHG Mitigation Strategies for Agriculture

As the temperature increases during summer, the equatorial regions get hotter resulting in damaging effects on the ecosystems. This necessitates the need to reduce the emission or trap the gases from the atmosphere to lessen the effects of GHGs.

Mitigation strategies involve two processes i.e. to reduce the emission and to increase the carbon sink in form of soil organic matter (SOM). Mitigation from agricultural soil involves the processes that enhance the soil carbon content, make use of applied nitrogen fertilizers efficiently by the plants, cause less soil disturbance, enhance photosynthesis, etc. The most effective mitigation measure is the amendment of organic matter to the soil. Following are the mitigation measures that are effective in reducing GHG emissions.

14.8.1 Reducing Tillage Frequency

It has been reported that no-till condition or reduced tilling leads to low flux of GHGs from soil as compared to conventional tillage (Gregorich et al. 2005; Nath et al. 2017; Pandey et al. 2012). Tilling of soil results in loosening and shattering of aggregates and thus soil organic matter decomposition and soil respiration are enhanced. The loss of soil water and disturbance in the microbial community lead to higher fluxes of GHGs under tilling, but no tilling also reduce the productivity of the soil (Soane et al. 2012). Under no tillage conditions, methanotrophic activity is more favored than conventional tillage leading to a reduction in CH_4 emission (Pandey et al. 2012).

14.8.2 Biochar Amendment

Application of biochar obtained from pyrolysis of straw and other crop residues is found to be an effective measure to enhance soil organic carbon (SOC) to improve the soil quality and to increase the plant productivity (Sohi et al. 2010). Zhang et al. (2010) reported 40–51% and 21–28% reductions in N_2O emission with and without N fertilizer application, respectively, whereas the CH_4 flux was increased after wheat straw biochar amendment. Karhu et al. (2011) reported reduced fluxes of CO_2, CH_4, and N_2O from an agricultural field after biochar application. Although biochar cannot be always used for the mitigation of GHGs, enhanced emission has also been reported on biochar amendment (Junna et al. 2014). The effects of biochar depend on many factors like biochar properties, application rates, soil texture, constituents of the soil, and their interactions (Cayuela et al. 2014).

14.8.3 Agronomic Practices

Improved crop varieties, deeply rooted plants, and better management of residues reduce GHG emissions (Smith et al. 2008). Different agronomic practices that enhance the plant productivity, high growth rate and higher biomass lead to increase in soil organic carbon (Abbas et al. 2017). The cover crops, catch crops, and crop rotation with leguminous crops are reported to provide carbon to the soil (Freibauer et al. 2004; Smith et al. 2008). Application of straw is reported to reduce N_2O

emission (Ma et al. 2007). Bare fallow land also causes more GHG fluxes (Freibauer et al. 2004). SOC in the soil is enhanced by high plant biodiversity, which also improves the soil structure. Organic polymers produced by soil biota help in formation and stabilization of aggregates (Lal 2004). Soil erosion decreases SOC. Nutrient cycling, biological nitrogen fixation, and other agro-ecological processes can be used to reduce GHG emissions (Thomson et al. 2012). Agroforestry results in a higher quantity of SOC in the deeper layer of soil as compared to crop cultivation. Soil microbial diversity enhanced due to tree plantation, which caused a positive effect on soil carbon sequestration (Abbas et al. 2017). In rice-wheat cropping system, application of neem oil coated urea, intermittent irrigation of rice crop, and no-tillage before wheat crop reduce the global warming potential (GWP) of the system (Gupta et al. 2016). Direct seeded rice reduced the GHG emissions effectively compared to transplanted rice (Gupta et al. 2016; Peyron et al. 2016). The ground cover rice production system is an effective measure to reduce GHG emissions as compared to the conventional rice production system (Yao et al. 2017).

14.8.4 Efficient Fertilizer Uses and Nutrient Management

Nutrient management is important to sequester carbon in the soil especially in the form of manure and compost than as an inorganic fertilizer. Fertilizers applied are not used by the plants effectively. Neem oil-coated urea has been reported to effectively reduce N_2O and CH_4 emissions as neem oil inhibits the nitrification process and enhances the population of methanotrophs (Gupta et al. 2016). Real-time N management techniques like leaf color chart (Bhatia et al. 2012) and greenseeker (Nath et al. 2017) based N application are found to be effective in reducing the emission as well as to enhance the nitrogen use efficiency. Leaf color chart-based urea application not only reduced GWP of rice-wheat cropping system but also increased the yield (Bhatia et al. 2012). Leguminous crops and organic manure can be used to enhance the productivity in place of inorganic N fertilizers, which enhance the GHG flux (Mosier et al. 2002). Manure application for a longer time strengthened the SOC pool and improved aggregates for a longer period (Thomson et al. 2012). Fertilizer, when applied in depth of the soil profile, leads to low emission (Liu et al. 2006; Yao et al. 2017). By using nitrification inhibitor technology, avoiding unnecessary external inputs to the soil, increasing soil pH by using lime to reduce denitrification, the fluxes of N_2O can be reduced (Thomson et al. 2012).

14.8.5 Irrigation Management

Irrigation management also influences GHG emission mainly in rice field. In drought-prone areas, proper water management practices enhance SOC by increasing the biomass (Lal 2004). Islam et al. (2018) observed about 90% reduction in CH_4 emission when practising early season drainage as compared to conventional flooding, while N_2O emission was higher. Emission from soil is significantly reduced when there is drought-like condition and the soil acts as a sink for N_2O (Goldberg and Gebauer 2009). Irrigation enhanced soil organic matter in the dry areas (Denef et al. 2008). The practices that increase SOC can decrease GHG emissions.

14.9 Conclusion

The agricultural sector directly or indirectly emits a significant proportion of GHGs and thus contributes to climate changes. Emissions of GHGs from soil mainly CO_2, CH_4, and N_2O are influenced by many biological and abiological factors acting simultaneously in nature. Excessive use of chemicals, tilling of fields, improper irrigation, etc., enhance GHG emissions. Rice fields are a major contributor to CH_4 emission. Wetting and drying cycles of soil emit a significant proportion of N_2O. High temperature provides favorable conditions for GHG emissions likewise high moisture content in soil and fine-textured soil maintain anaerobic conditions and thus emit comparatively higher GHGs. GHG emissions are low at high pH as well as low salinity. Nutrient availability enhances N_2O emission depending upon anaerobicity, C/N ratio, and active growth of microbes. Several factors influence the soil to act as a source or a sink for GHGs. Increased GHGs in the atmosphere affect the plant growth positively as well as negatively. A high CO_2 concentration increases the productivity of plant by increasing the photosynthetic rate and reducing transpiration, whereas the nutritional value is deteriorated. Different mitigation strategies can be adapted to reduce the GHG emissions from agricultural lands like reduced tilling, periodic irrigation, proper use of fertilizers, better crop varieties, and other agronomic practices depending upon the crop type and local environmental conditions.

Acknowledgements The authors are thankful to the Head, Department of Botany, Coordinators DST FIST, CAS, ISLS for laboratory and library facilities. Financial support from APN (Asia Pacific Network) project (CRRP2016-09MY-Lokupitaiya) and UGC JRF & SRF to Bhavna Jaiswal are also acknowledged.

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