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Trends in Greenhouse Gas Emissions from Agriculture Since 1960s and Mitigation

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ABSTRACT

India, the country with second highest populatiopn and third highest greenhouse gas emissionhas the dual responsibility of feeding the growing population, on one hand and minimizing greenhouse gas emiaaion on the other. In order to produce greater quantity of food, it has to apply fair quentity of agric-inputs, however to diminish the impact of agriculkture on climate through less greenhouse gases (GHGs) production, it shall reduce the application of agricultural production inputs. In order to devise and implement the strategies for minimizing the GHGs emission, it is essential to understand various dimensions of emission of GHGs from agriculture.Therefore, in the present investigation, an attempt has been made to provide holistic view of the GHG emissions by India and the world and the contribution of different agricultural emissions sub-domins towards the total amount of GHG emissions from agriculture at both global and national ievel so as to comprehend the measures required for mitigation of agricultural GHG emissions. It is expacted that this study will help the researchers and policy makers of India in strategic planning for mitigating GHGs emission from agriculture.

Keywords : Greenhouse gases, Nitrous oxide, Methane, Agriculture, Mitigation strategies.

INTRODUCTION

Agriculture is next only to the energy seetor in terms of its contribution towards climate change due to greenhouse gases emission resulting from increasing use of fertilizers and agri-inputs for crop production and mounting livestock population and their management(PAthak et al. 2014). It has been documented that agriculture and associated land use changes emit about one-fourth of the carbon dioxide into the atmos through deforestation, soil organic carbon depletion, machine and fertilizer use; half of the methane through livestock and rice cultivation and three-fourth of nitroous oxide through fertilizer application and manured management. The agricultural GHG emissions consist of non-CO_2 gases namely nitroous oxide (N_2O) and methane (CH_4). In develiping countries like India, the majority of agricultural GHG emission occurs at the primary production stage (Pathak et al. 2010), however other agricultuiral activities e.g. land clearing, irrigation,

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animal husbandry, fisheries and aquaculture also have a significant impact on GHGs emission (IPCC 2007a, b). It has been documend that increase in agricultural production over the last five decaded has resulted in nearly doubling the emission of GHG emission from agriculture, forestry and fisheries and this sector is responsible for 18% of total national GHG emissions in India (INCCA 2007). The influence of cropland agriculture on global warming has been reported to be due to related direct and indirect GHG emissions from carbon (C) and nitrogen (N) dynamics (wang et al. 2013), however the relative contribution of Indian agriculture to total GHGs GHGs emission from all sectors of the country has decreased from 33% in 1970 to 15% in 2010 (Pathak et al. 2014).

India, being the third largest GHG emitter in the world (Sapkota et al. 2019) after China and the United States and the second most populous country after China faces the challenge of feeding the growing population through agricultural production, on one hand and of reducing greenhouse gas emission,on the other hand. Due to these twin responsibilities, there is a need for adoption of mitigation strategies so as to curtail the emission of GHGs from agricultiral eector while fulfilling the food requirement of large population. The significance of agriculture and allied sectors to total GHGs emission in India has been well recognized and creating sustainable and climate-reslient agricultural systems has been considered to be the priority area as part of India's plan to meet its ambitious pledge to United Nation Farmework Convention on Climate Change (UNFCCC) for reducing the emission intensity of its GDP by upto 35% by 2030, compared to 2005 levels.

In order to comprehend the measures for mitigation of greenhouse gases (GHGs), it is essential to analyze the major source4s contributing to these enission and understand the trends in emission of GHGs and their drivers. therefore, the pre sent study gives a comparative account of the pattem of total agricultural GHGs emission and per capita agricultural GHGs emission, contribution of India agriculture to global agricultural GHGs emission and various agricultural emission sub-domains contributing to toptal GHGs emission, nitrous oxide and methane emissions since 1960s at the national and global level. It attempts to provide a holistic view of the contribution of different agricultural emissions sub-domains towards the total amount of GHG emissions from agriculture in India and the global level and various measures required for mitigation of agricultural GHG enissions. It is expected that this study will help the researchers and policy makers of India in strategic planning for mittgating GHGs emission.

Data retrieval and calculation for GHG estimation

All the data used for this research study have been retrieved from the Food and Agriculture Organization (FAO) database and the decadal averages calculated and graphs and figures plotted using the standard statisticaltools. The emissions produced in different agricultural emissions sub-domains i.e. enteric fermentation, manure management, rice cultivation, synthetic fertilizers, manure applied to soils, manure left pastures, crop residues,cultivation of organic soils, burning of crop residues and burning of savanna and their contribution towar5ds N_2O and CH_4 emissions are taken consideration in the present investigation.

Trends in GHGs emission at national and global level

There has been a continuous increase in the agricultural greenhouse gases emission in India as well as the world. As may be seen from Fig. 1, the highest and lowest increase in GHG emission over the previons decade had been fpound to be during 197s to 1980s and 2000s to 2010s,respectively in India. The decadal average GHG emissions increase that took place during the said periods was 19.2% and 7.9%, respectively. At the global level, the maximum and minimum rise in the level of agricultural GHG emission had been observed during 1960s to 1970s and 1990s to 2000s with the value of 19.14% and 4.26% respectively. Taking an account of the percent increase in agricultural GHG emissions since 1960s, it has been found that the emission has enhanced by 80.4% in India and 73.9% percent at the global level by 2010s (Fig. 2).

Figure 3 shows that the decadal average of per capita GHG emission has decreased over time at the

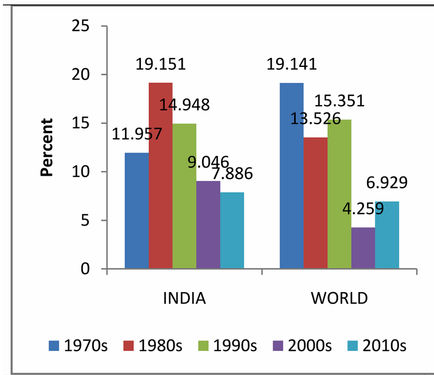

Fig 1

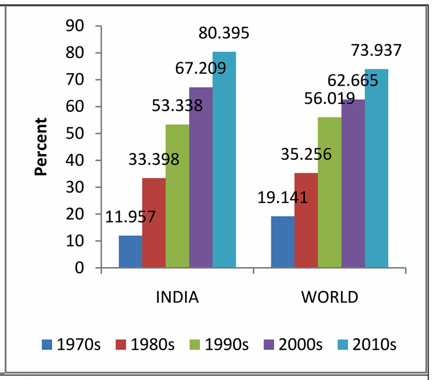

Fig 2

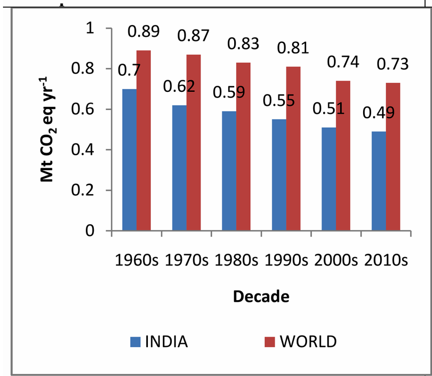

Fig 3

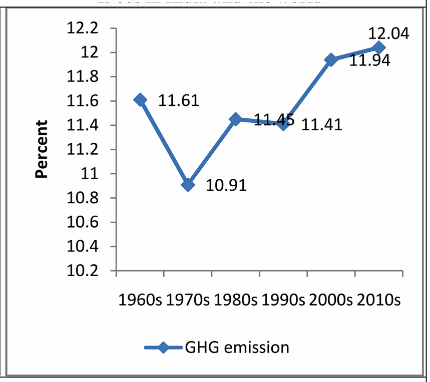

Fig 4

Fig. 1. Percent increase in total GHG emission over previous decade in India and the world. **Fig. 2.** Percent increase in total GHG emission over 1960s in India and the world. **Fig. 3.** Decadal average of per capita GHG emission in India and the world. **Fig. 4.** Decadal average of the percent contribution of India to total GHG emission in the world.

global as well as national level. At the global level, per capita GHG emission has decreased over time at the global as well as national level. At the global level, per capita emission has continuously decreased from 0.89 to 0.73 Mt CO_2 eq cap^{-1}during 1960s to 2010s. Similar reend has been observed in India wherein it has been found that per capita GHG emission has decreased from 0.70 to 0.49 Mt CO_2 eq cap $^{-1}$ during the period of analysis. It is cleatly evident from the figure that the level of per capita GHG emission from agriculture in India has always been less than the global average. The decrease in per capita GHG emission over the period of time may be attributed to increased efficiencies of food production systems during the last six decades (Tubiello 2019).

As shown in Fig. 4 given below, the share of GHG emissions from Indian agriculture towards total agricultural GHG emission at global level was 11.61% in 1960s that has been fluctuating over the period of analysis and the value has reached its peak i.e. 12.04% during 2010s.

As can be seen in Table 1, total GHG emission from agriculture in India has increased from the level of 349.77 Mt CO_2 eq yr^{-1} in 1960s to 630.97 Mt CO_2 yr^{-1} in 2010s i.e. there has been an increase of more than 80% in GHG emission from 1960s to 2010s. Similarly, the global GHG emission from agriculture has increased from 3011.7 Mt CO_2 eq yr^{-1} in 1960s to 5238.46 Mt CO_2 eq yr^{-1} in 2010s which is an increases of 73.9% over last sis decades. It iselear from Fig. 5 that methane has been the major contributor towards total GHG emissions, however

Table 1. Decadal average of GHG emission from agriculture in India and the world (Mt CO_2 eq yr^{-1}). Source :FAOSTAT database (FAO 2019), domain Emissions-Agriculture.

Decade	India			World		
	N_2O	CH_4	Total	N_2O	CH_4	Total
1960s	66.40	283.38	349.77	973.21	2038.49	3011,70
1970s	85.23	306.36	391.59	1277.20	2310.98	3588.18
1980s	119.88	346.71	466.59	1581.24	2492.27	4973.51
1990s	158.97	377.36	536.34	2001.88	2696.97	4698.85
2000s	189.18	395.67	684.85	2136.37	2762.62	4898.99
2010s	221.72	409.26	630.97	2347.73	2890.72	5238.46

its percent contribution towards total GHG emission from agriculture in India has decreased from 81.02% during 1960 to 64.86% during 2010s. On the other hand, the percent contribution of nitrous oxide to total GHG emission has been growing from 18.98% during 1960s to 35.14% during 2010s. During this period, nitrous oxide emission increased sharply from 66.4 Mt CO_2 eq yr^{-1} in 1960s to 221.72 Mt CO_2 eq yr^{-1} in 2010s which is an increase by 234% over the period of six decades and rise in methane emission has taken place from 283.38 Mt CO_2 eq yr^{-1} to 409.26 Mt CO_2 eq yr^{-1} i.e. an increase by 44.4% from 1960s to 2010s. Similar is the trend in GHG emission at global level where it has been found that methane has been the major contributor to total GHG emission from agriculture with 67.69% during 1960s and 55.18% during 2010s (Fig. 6) and the percent contribution of nitrous oxide kept on increasing and that of methane went decreasing in all the decades over analysis period. also, there has been an increase in nitrous oxide and methane emissions by 141 and 41.8%, respectively over the period of six decades at the global level during 1960s to 2010s.

The potential effect of methane and nitrous oxide is significantly higher than that of carbon dioside as methane and nitrous oxide have global warming potential of 21 and 310 times, respectively denoting higher heat-absorptive capacity than carbon dioxide per unit of weight (https//www.global.greenhouse-warming.com/glpbal-warming-potential.html).

Sub-domains of agricultural GHG emissions

The major component parts of agricultural emissions at the global as well as national levels include enteric fermentation, manure management, rice cultivation, synthetic fertilizers, manure applied to soils, manure left on pasture, crop residues, cultivation of organic soils, burning crop residues and burning Savanna. Over the period of analysis, the largest contributor to total GHG emisions from agriculture in India as well as the global level has been found to be enteric fermentation contributing 53% (186 Mt CO_2 eq yr^{-1}) during 1969s to 45% (285 Mt CO_2 eq yr^{-1}) during 2010s in India (Table 2, Fig 7) and 48.8% (1469 Mt CO_2 eq yr^{-1}) and 38.7% (2030 mt CO_2 eq yr^{-1}) during 1960s and 2010s, respectively at the global level

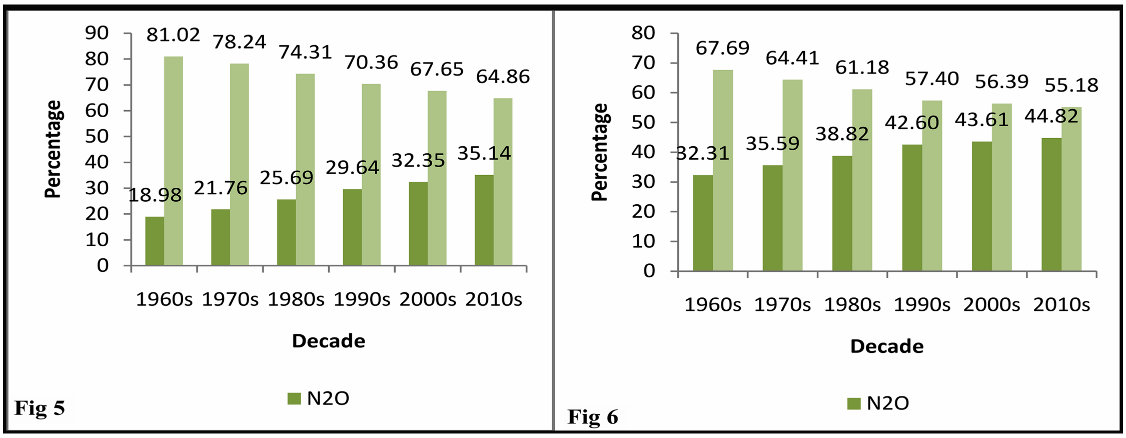

Fig. 5. Decadal average of the percent contribution of nitrogen oxide (N2O) and methane (CH_4 to total GHG emission from agriculture in India. **Fig. 6.** Decadal average of the percent contribution of nitrous oxide (N_2O) and methane (CH_4) to total GHG emission from agriculture intje world. Source : FAOSTAT database (FAO 2019), domain: Emissions-Agriculture.

Table 2. Decadal average of total GHG emission from agriculture (Mt CO_2 eq yr^{-1}) by activity in India. *Data for emision from cultivation organic soils and burming Sayama not available. source FAOSTAT database (FAO 2019), demain: Emissions-Agricultur.

Decade	Enteric dementati-on	Manure meanagem-ent	Rice cultiva-tion	Synthetic lertilizers	Manurc applied of soils	Manure left on pasture	Crop residues	Cultivation of organic soils	Burning crop residues	Burning-Savana	Total
1960s	186.04	17.70	80.26	5.10	9.02	37.96	11.17	*	2.53	*	349.77
1970s	201.25	19.48	86.22	16.75	9.88	41.72	13.39	*	2.91	*	391.59
1980s	233.96	23.00	90.68	37.40	11.70	50.34	16.28	*	3.11	*	466.59
1999s	256.44	25.58	96.23	64.33	13.09	56.37	19.51	0.77	3.36	0.64	536.34
2000s	273.58	27.44	95.82	85.42	14.46	61.90	21.44	0.77	3.53	0.48	584.85
2010s	285.24	28.57	96.56	110.41	15.29	65.13	24.69	0.77	3.80	0.51	630.97

Table 3. Decadal average of total GHG emission from agriculture (Mt CO^2 eq yr^{-1}) by activity in the world. *Data for emission from cultivation of organic soils and burning Savanna not available. Source : FAOSTAT database (FAO 2019), domain. Emissions-Agriculture.

Decade	Enteric dementati-on	Manure meanagem-ent	Rice cultiva-vation	Synthetic fertilizers	Manure applied soils	Manure left on pasture	Crop residues	Cultivation of organic soils	Burning crop residues	Burning-Savanna	Total
1960s	1468.53	266.98	396.69	134.20	136.44	492.34	95.57	*	21.16	*	3011.70
1960s	1672.36	304.63	443.95	295.86	159.12	568.82	120.39	*	23.25	*	3588.18
1980s	1813.54	328.76	456.77	460.73	177.05	627.73	142.71	*	24.29	*	4073.51
1990s	1853.75	327.48	477.48	506.62	174.16	685.65	156.47	121.06	25.05	371.12	4698.85
2000s	1930.24	327.23	492.85	588.58	176.12	759.70	176.42	123.19	26.37	298.30	4898.99
2010s	2029.55	341.08	518.48	697.04	186.75	524.29	206.11	127.53	29.50	278.14	5238.46

(Table 2, Fig. 7). Enteric fermentation is natural part of the digestive process of many numinants in which decomposition and fermentation of food is carried out by anaerobic microbes in the rumen. the process, not being 100% efficient leads to loss of food energy in the form of methane (https://cc.europa.eu/eurostat/statistics-explained/index.php?title=Archive:agriculture_greenhouse_gas_emission_statisties & oldid=158399)

The second largesat contributor to GHG emission from agriculture in India has continued to be rice cultivation during 1960s (22.9% 80 Mt CO_2 sq yr^{-1}) to 2000s (16.4%, 95.8 Mt CO_2 eq yr^{-1}, however synthetic fertilizers have taken over this position during 2010s (17.5%, 110.4 Mt CO_2 eq yr^{-1}). On the other hand, the position of second hargest contributor to total GHG emission from agriculture at the global level has been manure left on pasture during the period of analysis (Table 3). The synthetic fertilizers mainly nitrogenous fertilizers have not only become the second largest source of GHG emissions in India, their indiscriminate application also leads to an accumulation of nitrate in leafy vegetables to the level toxic to human health.

Table 4. Decadal average of nitrous oxide (N_2O)emission from agriculture (Mt CO_2 eq yr^{-1}) by activity in India. Source : FAOSTAT database (FAO 2019), domain: Emissions-Agriculture.

Decade	Manure management	Synthetic fertilizers	Manure applied to soils	Manure left on pasture	Crop residues	Cultivation of organic soils	Burning - crop residues	Burning - savanna	Total
1960s	2.45	5.10	9.02	37.96	11.17	*	0.70	*	66.40
1970s	2.69	16.75	9.88	41.72	13.39	*	0.80	*	85.23
1980s	3.20	37.40	11.70	50.34	16.28	*	0.86	*	119.88
1990s	3.59	64.33	13.09	56.37	19.51	0.77	0.93	0.37	158.97
2000s	3.94	85.42	14.46	61.90	21.44	0.77	0.98	0.27	189.18
2010s	4.08	110.41	15.29	65.13	24.69	0.77	1.05	0.29	221.72

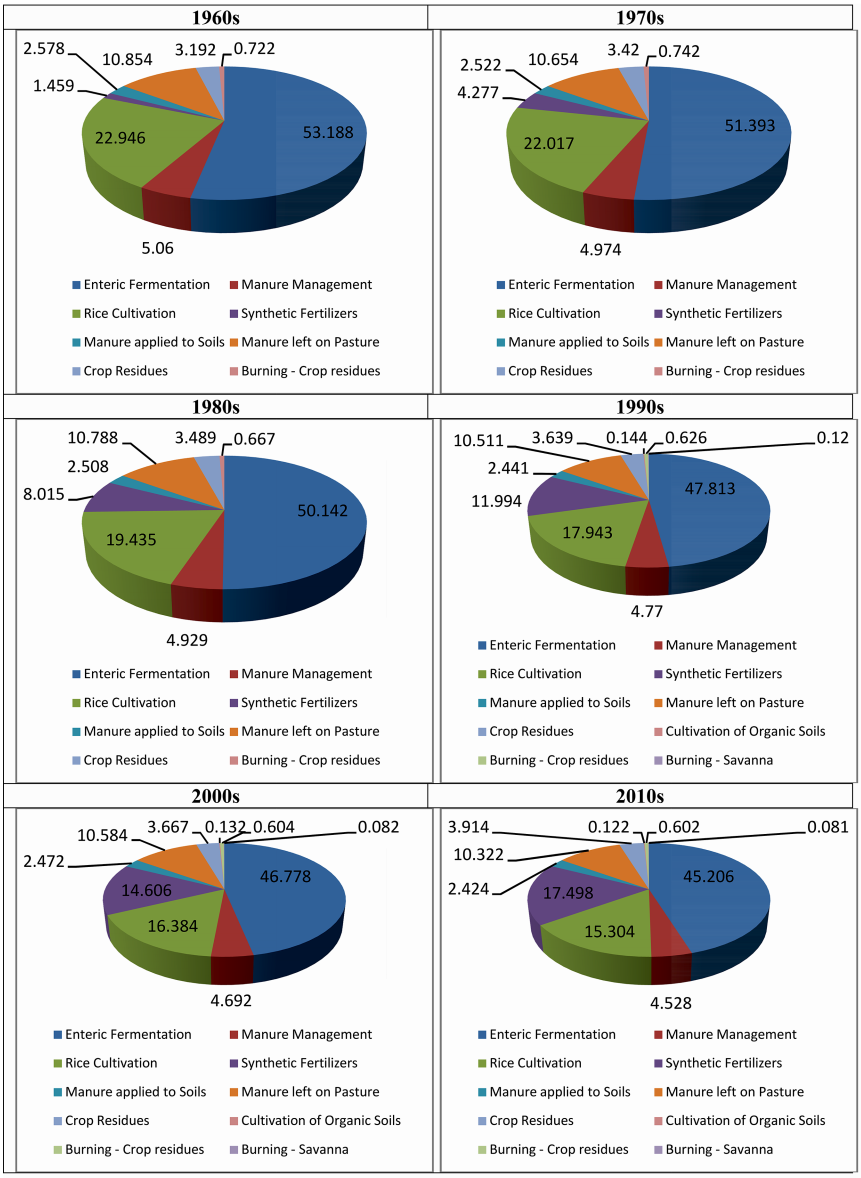

Fig. 7. Decadal average of the percent contribution of different activities to total GHG emission from agriculture in India. Source: FAOSTAT database (Fao 2019), domain Emissions-Agriculture.

In India, the next major contributors include manure include manure left on pasture and manure management contributing approximately 10% and 5%, respectively throughout the period of analysis. It is worth niting that the percent contribution of synthetic fertilizers to total GHG emission from agriculture was 1.5% only during 1960s and has sharply increased over the last six decades to 17.5% during 2010s and has now occupied the position of second largest contributor. Similar is the case at the global level where it has been found that synthetic fertilizers contributed merely 4.5% to total GHG emission from agriculture during 1960s and has reached the level of 13% in terms of its contribution during 2010s and

Table 5. Decadal average of nitrous oxide (N_2O) emission fron agriculture (Mt CO_2 eq yr^{-1}) by activity in the world. Source: FAOSTAT database (FAO 2019), domain Emissions-agriculture.

Decade	Manure management	Synthetic fertilizers	Manure applied to soils	Manure left on pasture	Crop residues	Coltivation of organic soils	Burning - crop residues	Buming - Savanna	Total
1960s	108.81	134.20	136.44	492.34	95.57	*	5.56	*	973.21
1970s	126.58	295.86	159.12	568.82	120.39	*	6.43	*	1277.20
1980s	137.13	460.73	137.05	627.73	142.71	*	6.72	*	1581.24
1990s	138.77	506.62	174.16	685.65	156.47	121.06	6.93	212.22	2001.88
2000s	134.51	588.58	176.12	759.70	176.42	123.19	7.30	170.56	2136.37
2010s	138.79	697.04	186.75	824.29	206.11	127.53	8.17	159.07	2347.73

Table 6. Decadal average of methane (CH_4) emission from agriculture (mt CO_2 eqyr^{-1}) by activity in India. Source : FAOSTAT detabase (FAC 2019), domain. Emissions- Agriculture.

Decade	Enteric fermentation	Manure management	Rice cultivation	Burning- crop residues	Burning - savanna	Total
1960s	186.04	15.25	80.26	1.83	*	283.38
1970s	201.25	16.79	86.22	2.10	*	306.36
1980s	233.96	19.80	90.68	2.25	*	346.71
1990s	256.44	21.99	96.21	2.43	0.28	377.36
2000s	273.58	23.50	95.82	2.55	0.20	395.67
2010s	285.24	24.49	96.56	2.75	0.22	409.26

is the third largest contributor to GHG emissions at global level. The other major contributor to global GHG agricultural emissions at the global level is rice cultivation (9.9%).

In view of the above, the increase in GHG emission during the period of study may be attributed to an increase in the use of synthetic fertilizers and other agric-inputs and the rising livestock population in the country.

Components of nitrous oxide emission from agriculture

Table 4 gives an overview of the decadal average of nitrous oxide (N_2O) emission from agriculture in India by various activities during the period of 1960s to 2010s. During 1960s, manure left on pasture had been the largest component for N_2O emission with 38 Mt CO_2 eq yr^{-1} (52%) followed by emission from crop residues (11.2 Mt CO_2 eq yr^{-1}, 16.8%), manure applied to soils (9.02 Mt CO_2 eq yr^{-1}, 13.6%) and synthetic fertilizers (5.10 Mt CO_2 eq yr^{-1} 7.7%. This pattern has changed drastically over the period of time i.e. synthetic fertilizers that occupied fourth position has risen to first position with an increase from 5.1 Mt CO_2 eq yr^{-1} (in 1960s) to 110.41 Mt CO_2 eq yr^{-1} (in 2010s) i.e. an increase by 2065% during last six decades. The next major contributors to nitrous oxide emission during 2010s include manure left on pasture

Table 7. Decadal average of methane (CH_4) emission from agriculture (Mt CO_2 eq yr^{-1}) by activity in the world. Source : FAOSTAT database (FAO 2019), domain: Emissions-Agriculture.

Decade	Enteric fermentation	Manure management	Rice cultivation	Buming - crop residues	Buming- Savanna	Total
1960s	1468.53	158.17	396.49	15.30	*	2038.49
1970s	1672.16	178.05	443.95	16.81	*	2310.98
1980s	1813.54	191.62	456.77	17.56	*	2492.27
1990a	1853.75	188.71	477.48	18.12	158.90	2696.97
2000s	1930.24	192.72	492.85	19.07	127.74	2762.62
2010s	2029.55	202.28	518.48	21.34	119.07	2890.72

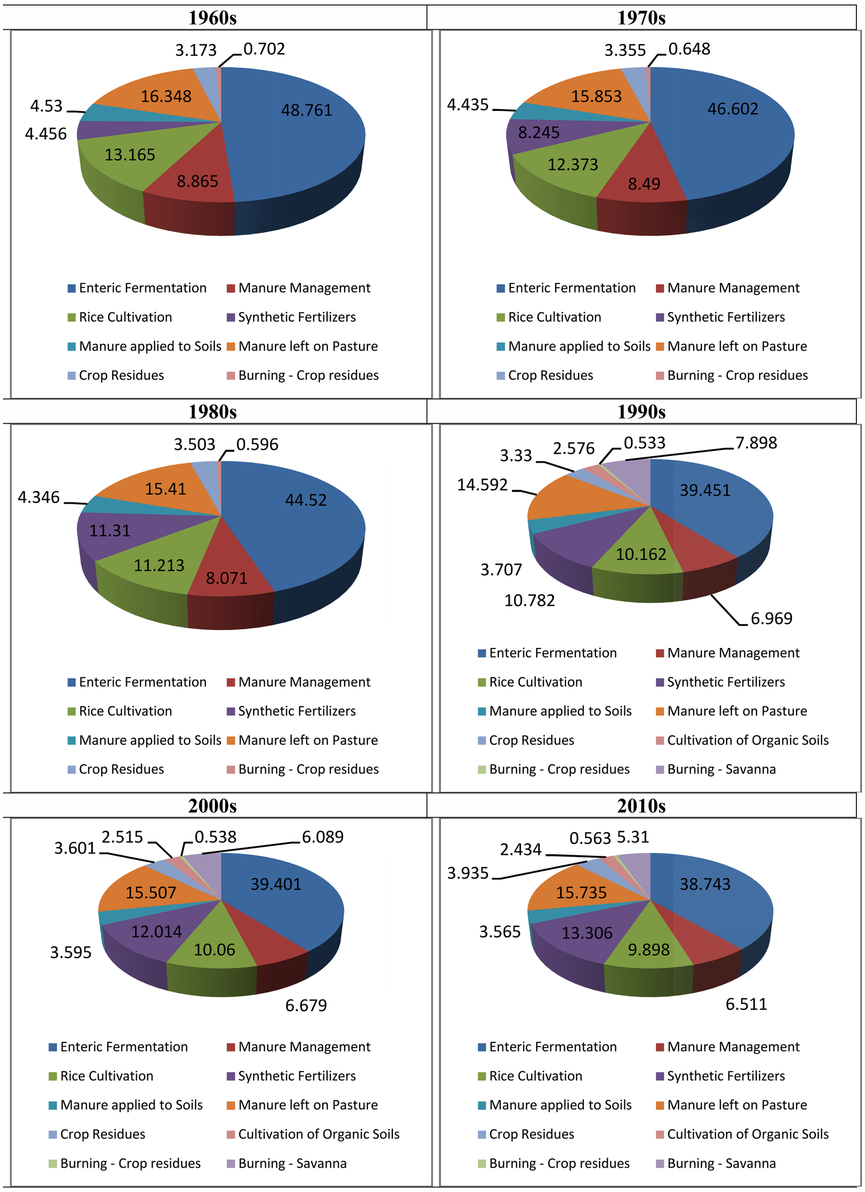

Fig. 8. Decadal average of the percent contribution of different activities to total GHG emission from agriculture in the world. Source: FAOSTAT database (FAO 2019), domain : Emissions-Agriculture.

(29.4%), crop residues (11.1%) and manure applied to soils (6.9%) Figs 8 and 9).

Table 5 and Fig. 10 show that the maximum amount of N_2O emission at the global level had taken place from manure left on pasture (50.6% 492 Mt CO^2 eq yr^{-1}) followed by manure applied to soils (14%), synthetic fertilizers (13.8%), manure management (11.2%) and crop residues (9.8%) during 1960s. IT is worth noting that emission from manure left on pasture continues to occupt the highest position in terms of its share towards nitrous oxide emission

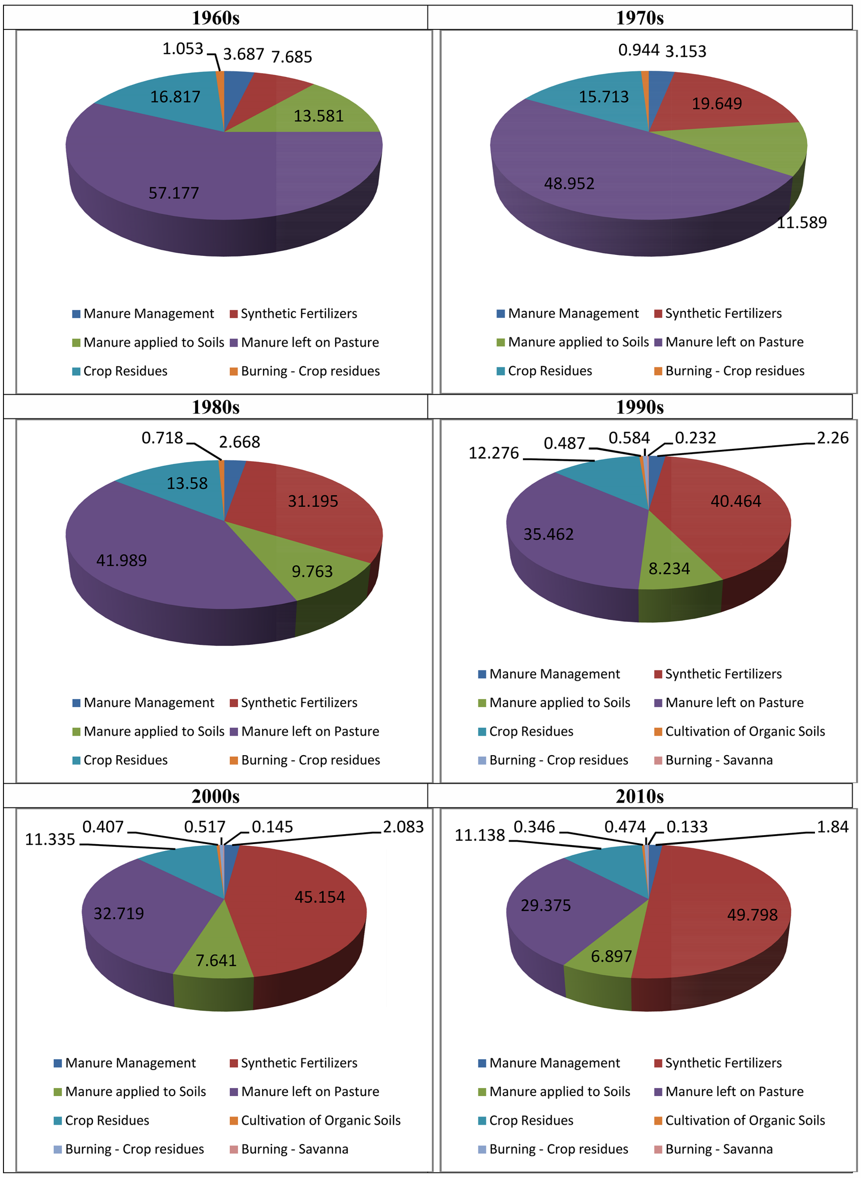

Fig. 9. Decadal average of the percent contribution of different activities to nitrous oxide (N_2O) emission from agriculture in India. Source : FAOSTAT database (FAO 2019), domain: emissions-Agriculture.

during 2010s, however synthetic fertilizers has replaced manure applied to soils from second position.

Components of methane emission from agriculture

Tables 6 and 7 give an account of the various agricultural activities that lead to emission of GHG in the form of methane (CH4) in India and the world. It has been found that enteric fermentation, manure management, rice cultivation, burning crop residues and burning Savanna are the sources of Agricultural greenhouse gas emissions in the form of methane. The available data show that enteric fermentation and rice cultivation continued to be the highest contrib-

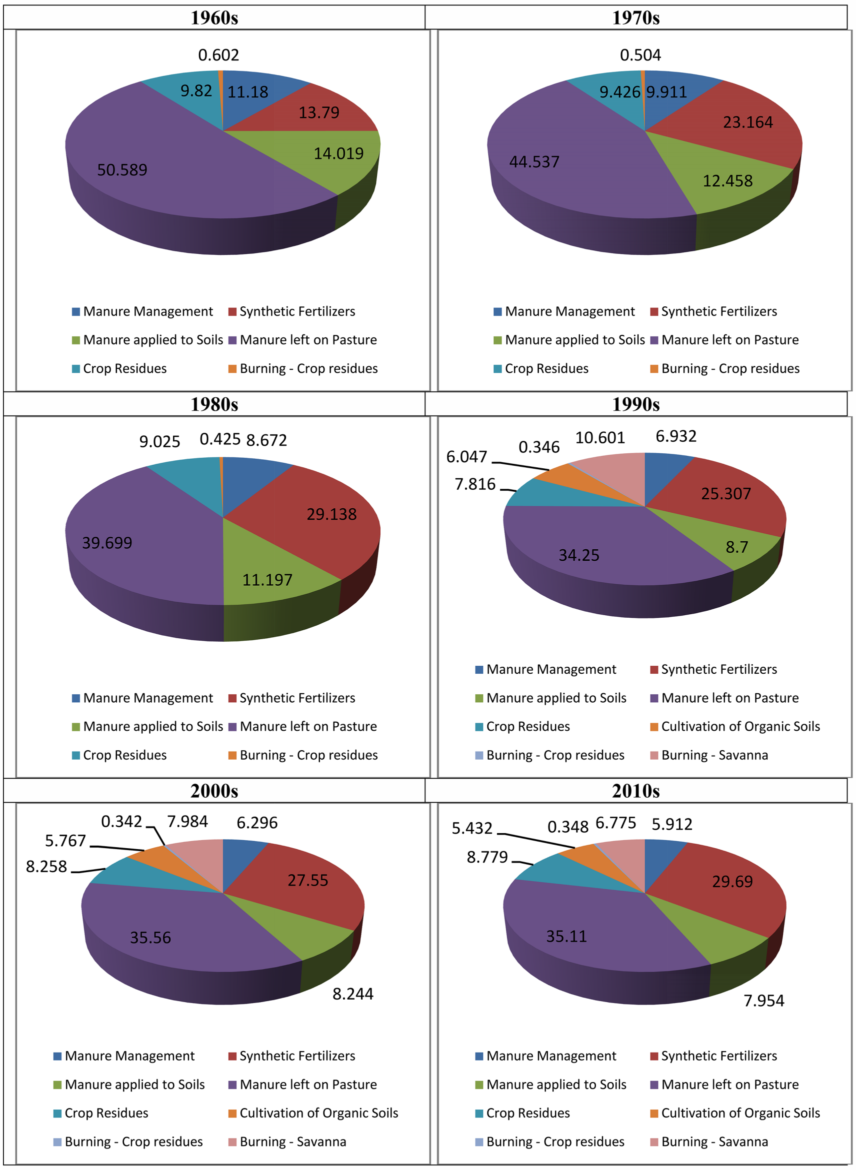

Fig. 10. Decadal average of the percent contribution of different activities to nitrous oxide (N_2O) emission from agriculture in the world. Source : FAOSTAT database (FAO 2019), domain: emissions-Agriculture.

utors to methane emission at the national as well as global level throughout the period of study. Studying the global averages, it has been found that the percent contribution of enteric fermentation as well as rice cultivation towards methane emission has come down from 72% and 19.5% during 1960s to 70.2% and 17.9% during 2010s, respectively. In India, the share of enteric fermentation has increased from 65.7 to 69.7% during the above said period, however that of rice cultivation has declined from 28.3% 23.6% (Figs. 11 and 12).

Given the overall scenario of GHG emissions at national and global level, whereby it has been

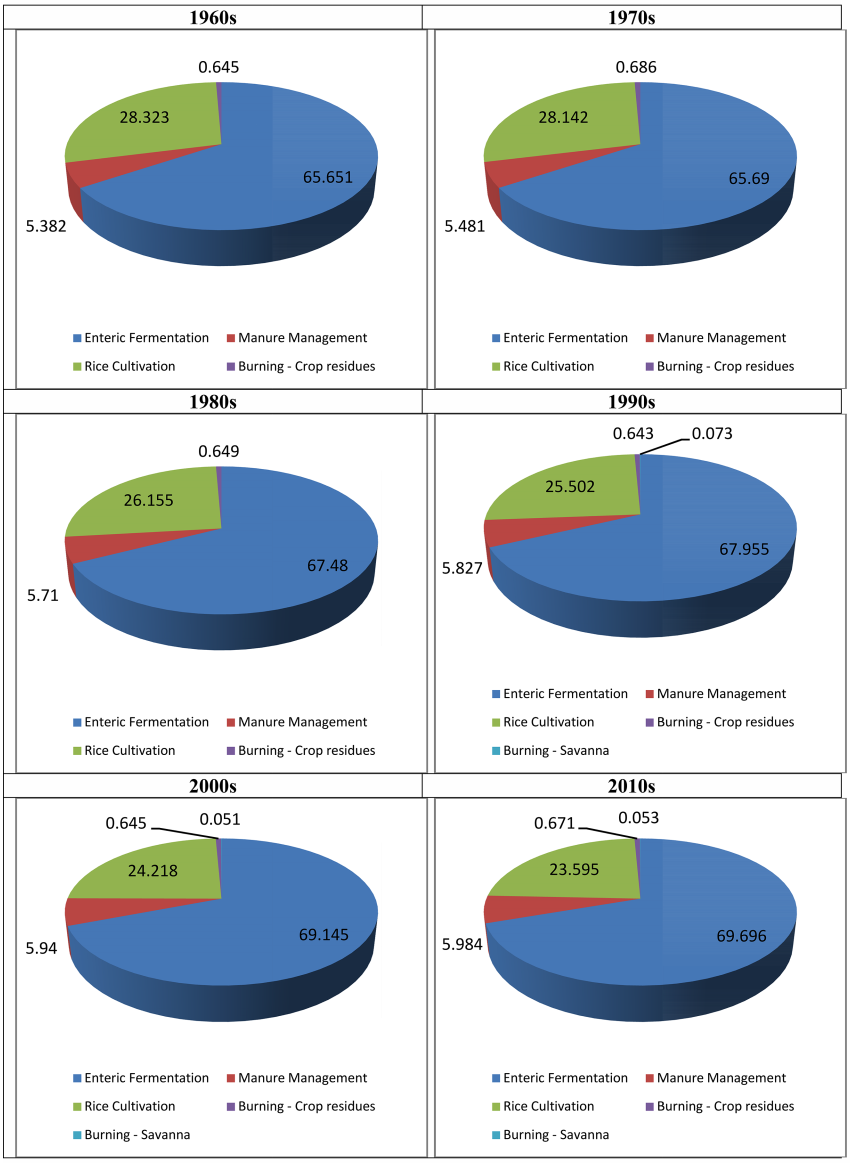

Fig. 11. Decadal average of the percent contribution of different activities to methane (CH_4) emission from agriculture in India. Source: FAOSTAT database (FAO 2019), domain: Emissions-Agriculture.

found that there has been a continuous increase in the emission of GHG from agricultural sector, it is imperative to explore the strategies so as to mitigate the emissions from this sector. The ensuing section, therefore discusses various mitigation methods that have been worked upon by many researchers in order to develop the practices, the adoption of which may lead to decrease in the emission of greenhouse gases from agriculture sector.

Mitigation of GHGs emission

It has been reported that agriculture is not only the source of GHGs emission but can also mitigate GHGs emission through reduction in nitroous oxide and methane emissions to the atmosphere, as well

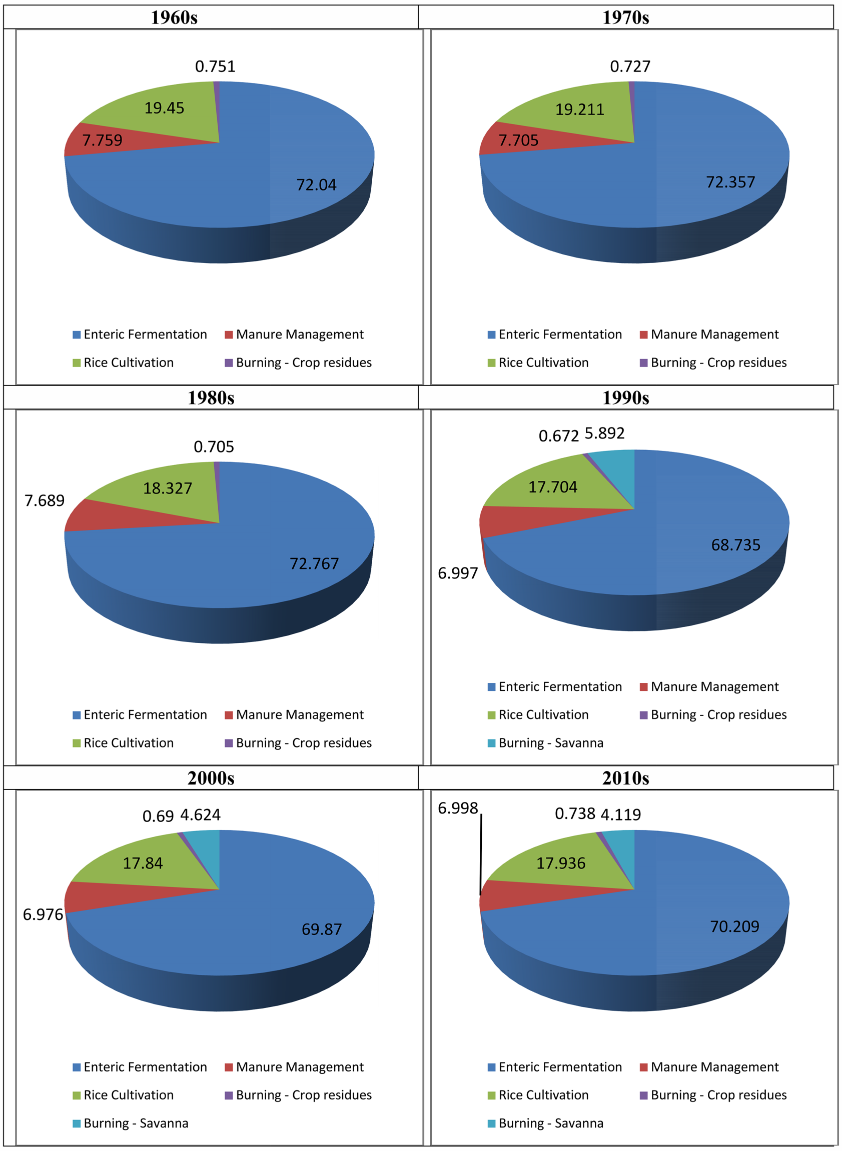

Fig. 12. Decadal average of the percent contribution of different activities to methane (CH_4) emission from agriculture in the world. Source: FAOSTAT database (FAO 2019), domain: Emissions-Agriculture.

as through sequestration of atmospheric carbon into plant biomass and soil (Pathak et al. 2014) and India has the potential to cut 18% of its annual greenhouse gas emissions from agriculture and livestock (Sapkota et al. 2017). There are various measures that can be adopted for mitigating GHGs emission and those which can be implemented without imposing any cost include efficient use of fertilizers, adoption of zero-tillage farming and improvement in management of water used for irrigation of rice crops. Three mechanisms have been suggested by the researchers for mitigation of GHGs i.e.. reduction in emissions, enhancement of removals and avoiding emissions that can be achieved through cropland, soil and livestock management and the mitigation strategies for reduction of methane and nitrous oxide emission from livestock have also been categorized into three groups i.e.improved feeding practices, use of specific agents or dietary additives and longer term management changes and animal breeding (IPCC 2007a, b).

Some of the important mitigation practices may be discussed as follows:

Nutrient management : Adoption of precision nutrient management i.e. application of fertilizers on the basis of precise estimate of plant demand in the right form and at the right time improves nutrient use efficiency that has great potential for GHG mitigation (Sapkota et al. 2019). Tailoring the addition of nutrients to plant uptake have been suggested to be effective in reducing nitrous oxide emissions. Adjustment in application rate and timing of the nutrients particularly, nitrogen just prior to plant uptake and their placement in the soil on the basis of precise estimates improve the efficiency of their uptake and utilization by the plants thereby improving nutrient use efficiency and reducing the emission of GHGs through volatilization. Use of leaf color chart for making decision about the time for application of nitrogenous fertilizers may also reduce emission of nitrous oxide and global warming potential by about 11-14% (Bhatia et al. 2012, Jain et al. 2013).

Crop residue management : Burning of crop residue on-site leads to release of methane and nitroous oxide and also generates hydrocarbon and reactive nitrogen, which react to form tropospheric zone. Avoidance of the burning of crop residues alsi avoids the emission of acrosols and GHGs generated from fire and enhances soil carbon (Sapkota et al. 2017), thereby mitigating GHG emission.

Water management : Nitrogen lost through drainage may be susceptible to get released in the atmosphere in the form of N_2O and proper drainage of croplands in humid regions may suppress N_2O emissions by improving aeration of the soil. Some of the water efficient technologies such as micro-irrigation, fertigation, sprinkler, microsprinkler irrigation, have been reported to possess considerable mitigation potential due to associated energy usage for crop production (Rolaniya et al. 2016).

Rice management : Effective irrigation management in rice fields by converting continuously flooded rice areas into alternate wetting and drying and promotion of laser levelling of fields reduce methane emissions (Jat et al. 2015). As reported by various researchers, draining of wetland rice once or several times during the growing season and letting the field dry after irrigating rather than keeping the field continuously flooded reduces methane emissions (Sapkota et al. 2019).

Agronomy : Adoption of cropping systems such as rotations with legume crops that reduce the dependence on nitrogenous fertilizers, pesticides and other inputs reduces GHGs emissions, Improved agronomic paractices that include temporary vegetative cover between successive agricultural crops, or between rows of tree or crops have also been recommended in order to extract available and unused nitrogen in the soil that may reduce emission of N_2O (IPCC 2007a, b).

Use of nitrification inhibitors : One of the most efficient management practions for reducing nitrous oxide emission is site-specific nutrient management and use of nitrification inhibitors e.g. coated calcium carbide and dicyaandiamide, plant-derived organics (neem oil, neem cake and karanja seed extract). (Pathak et al. 2014).

Conservation agriculture : It has been suggested that adoption of resource-conserving technologies e.g. zero or minimum tillage with direct seeding, permanent of semi permanent residue over, crop rotations, possess the potential to enhance the sustainability of agriculture by conserving the resource base and mitigating GHGs emissions (Pathak et al. 2014).

Set aside and land cover (use) change : It has been suggested that reversion of cropland to another land cover, similar to that of native vegetation is one of the mast effective methods of reducing emissions. such conversion leads to an increase in carbon storage and can occur over the entire land area (set -asides), or in localized spots, such as grassed waterways, field margins, or shelter belts (IPCC 2007a, b), however this option may be used only on surplus agricultural land or on croplands of marginal productivity as it leads to loss of agricultural productivity.

Reduced/Zero-tllage : Zero tillage technique in which farmers minimize the disturbance of the soil has been suggested to enhance carbob sequestration, reduce fuel consumption and mitigate GHG emissions. Due to tillage, an increase in the loss of soil carbon takes place due to enhanced decomposition and crosion and reduced or no tillage in agriculture may result in soil carbon gain, although not always (IPCC 2007a, b).

Restoration of degraded land: The mitigation of GHG emission has also been suggested to take place through restoration of land degraded by erosion, excessive distirbance, organic matter loss, salinization, acidification. Restoration of such land for cultivation has the potential to increase carbon storage through increased photosynthesis and reduced soil crosion loss as well as reducing dependency on fossil fuels if grown with bioenergy crops (Jat et al. 2016).

High performance animal selection : It has beenreported that methane output per unit of animal product may be reduced by increasing productivity through breeding and better management practices.

Improved feeding practice : There are a range of diet and other management interventions that improve the efficiency of feed conversion, in crease livestock productivity and reduce emissions. Feeding highly digestible fodder such as green fodder and energy-dense food i.e. increased concentrate feeding have considerable potential for mitigating GHG emission from the livestock sector of India with less developed production systems and very little grains fed to animals> Improving the pasture quality may reduce the proportion of energy lost as methane and optimizing protein intake may reduce N excretion and nitrous oxide emissions (IPCC 2007a, b, Verchot 2014).

Use of dictary additives :The dietary additives that suppress methanogenesis include ionophores, halogenated compounds, novel plant compounds such as condensed tannins, saponins or essential oils, propionate precursors such as fumarate or malate, vaccines against methanogenicbacteria however the effects of some of these agents are often transitort and they can have side-effects too (IPCC 2007a, b, Verchot 2014).

Manure management: Emission of methane from manure stored in lagoons or tanks can be reduced through various means such as cooling, use of solid covers, mechanical separation of solids from slurry, capturing of emitted C_4 and the methane obtained on anacrobic digestion of manure may be used as a renewable source of energy. To some extent, emissions from manure might be curtailed by composting the manure (IPCC 2007a, b, Verchot 2014).

Although a number of practices as discussed above have been recommended by various researchers, there is a need for further investigation of the relative mitigation potential of these strategies, their feasibility of implementation, associated environmental risks, challenges, barriers and the opportunities involved, their contribution to sustainable development and their impact on the whole life-cycle of GHG emissions.

CONCLUSION

In the present study, it has beenfound that agricultural GHG emissions have been increasing continuously at the global as well as national level over the last six decades. Although, the per capita GHG emission level of India is lower than the global average, the situation is alarming as the percent contribution of the country towards global agricultural GHG emissions have reached its peak during 2010s. Moreover, synthetic fertilizers that have beenused indiscriminately by the farmers as insurance for good crop yield have reached secondposition (Next only to enteric fermentation) in terms of their contribution towards total agricultural GHG emissions during 2010s. Also, the percent contribution of nitrous oxide towards total agricultural GHG emissions has been increasing continuously at the national as well as global level. Therefore, it may be concluded that there is an urgent need to adopt the strategies at the national as well as global level that may mitigate the GHGs emissions associated with production inputs and improve the resource use efficiency however, further investigation needs to be undertaken in order to understand the holistic impact of mitigation strategies on the complete life-cycle of agricultural GHG emissions.

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