

# Contribution of Agriculture Sector to Climate Change

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## Abstract

Agriculture sector is a potential contributor to the total green house gas (GHG) emission with a share of about 24 % (IPCC, AR5 to be released) of the total anthropogenic emission, and a growing global population means that agricultural production will remain high if food demands are to be met. At the same time, there is a huge carbon sink potential in this sector including land use, land-use change, and forestry sector. For over four decades, evidence has been growing that the accumulation of GHGs in the upper atmosphere is leading to changes in climate, particularly increases in temperature. Average global surface temperature increased by  $0.6 \pm 0.2$  °C over the twentieth century and is projected to rise by 0.3–2.5 °C in the next 50 years and 1.4–5.8 °C in the next century (IPCC, Climate change: synthesis report; summary for policymakers. Available: [http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4\\_syr\\_spm.pdf](http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf), 2007). In the recent report of IPCC AR5 (yet to be released), it has been observed that warming will continue beyond 2100 under all representative concentration pathways (RCP) scenarios except RCP 2.6. Temperature increase is likely to exceed 1.5 °C relative to 1850–1900 for all RCP scenarios except RCP 2.6. It is likely to exceed 2 °C for RCP 6.0 and RCP 8.5 (Pachauri, Conclusions of the IPCC working group I fifth assessment report, AR4, SREX and SRREN, Warsaw, 11 November 2013). Agriculture is a potential source and sink to GHGs in the atmosphere. It is a source for three primary GHGs: CO<sub>2</sub>, N<sub>2</sub>O, and CH<sub>4</sub> and sink for atmospheric CO<sub>2</sub>. The two broad anthropogenic sources of GHG emission from agriculture are the energy use in agriculture (manufacture and use of agricultural inputs and farm machinery) and the management of agricultural land. Mitigation methods to reduce emissions from this sector are thus required,

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along with identification and quantification of emission sources, so that the agricultural community can act and measure its progress. This chapter focuses on different sources of GHG emission from agriculture sector and their key mitigation strategies.

### Keywords

GHG emission • Agriculture sector • Livestock • Mitigation strategies

## 3.1 Introduction

A continued rise in concentration of the greenhouse gases (GHGs) has led to enhanced greenhouse effect resulting in global warming and global climate change. Globally, GHG emission has increased by about 75 % since 1970. Looking at the total source of GHGs at present CO<sub>2</sub> contributes 76 %, CH<sub>4</sub> about 16 %, N<sub>2</sub>O about 6 %, and the combined F-gases about 2 % (IPCC AR5, yet to be released). The impact of human activities on GHG emission through fossil fuel burning, agriculture, and industrial processes is important and familiar to people. The effects of GHG emissions on the ecological and socio-economic vulnerability have already been noticed and will continue to grow regionally and globally in the years to come (IPCC 2007; Pachauri 2013). Carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are the important GHGs that are monitored by the United Nations Framework Convention on Climate Change (UNFCCC 2008). Global GHG emissions due to human activities (anthropogenic) have grown since the beginning of the industrial revolution with an increase of 70 % between 1970 and 2004 (IPCC 2007). The radiative forcing of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O is very likely (>90 % probability) increasing at a faster rate during the current era than any other time in the last 10,000 years. This is because of the increase in the global abundance of the three key GHGs, namely, carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O), in the atmosphere. The concentrations of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O have increased markedly by 30 %, 145 %, and 15 %, respectively, as a result of

human activity since the period of industrial revolution (IPCC 2007). Management of agricultural land, land-use change, and forestry has a profound influence on atmospheric GHG concentration. The two broad anthropogenic sources of GHG emission from agriculture are the energy use in agriculture (manufacture and use of agricultural inputs and farm machinery) and the management of agricultural land. In the agriculture sector, besides the CO<sub>2</sub> emissions due to burning of crop and animal waste, the world's livestock population and rice fields are significant contributors to CH<sub>4</sub> emissions. An understanding of GHG emissions by sources and removal by sinks in agriculture is important to take appropriate mitigation and adaptation strategies and to estimate and create inventory of GHGs.

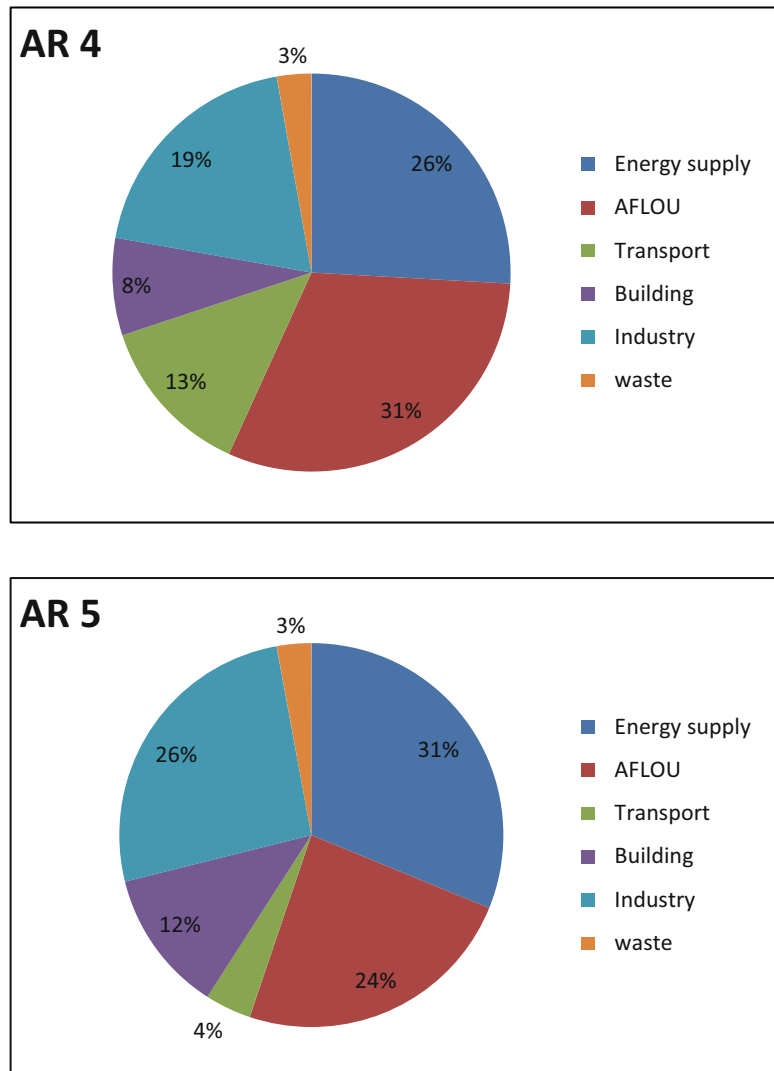
It is clear that the agriculture sector is increasing in size, but exactly how this is impacting on GHG emissions remains uncertain, as do the opportunities for mitigation. Within the scientific community there is increasing recognition that agriculture in general, and livestock production in particular, contribute significantly to GHG emissions (Bell et al. 2014; Bellarby et al. 2013; Galloway et al. 2007). As a result, the global agricultural community is committed to reducing emissions to safeguard the environment; however, it must simultaneously meet the demands of a growing human population and their increasing requirements for food high in quality and quantity. There is a need to improve the efficiency of agricultural production if we are to meet global food supply demands and decrease agriculture's impact on climate change. Quantification of the impacts that agriculture is having on the environment is thus of major importance. This chapter

illustrates the different sources and sinks of GHG from agriculture sector including forestry and land-use changes and their mitigation potential.

### 3.2 Sources and Sinks of GHG from Agriculture

Sectoral distribution of GHG emission comparing the emission levels at 2004 (AR4) and 2010 (AR5) is given in Fig. 3.1. By sector, the largest sources of GHGs were the sectors of energy production (mainly CO<sub>2</sub> from fossil fuel combustion) and agriculture, forestry, and other land use

(AFOLU) (mainly CH<sub>4</sub> and N<sub>2</sub>O). The contribution of AFOLU (agriculture, forestry, and other land use) to total emission has come down from 31 % (2004) to 24 % (2010). Identification of GHG sources and quantification of GHG emission from agriculture sector has passed through many phases of refinement. The 1996 IPCC inventory guidelines require emission reporting from the following six categories: energy, industrial processes, solvent and other product use, agriculture, land-use change and forestry (LUCF), and waste (Crosson et al. 2011). These categories were revised in the 1996 revised guidelines, where LUCF was expanded to include

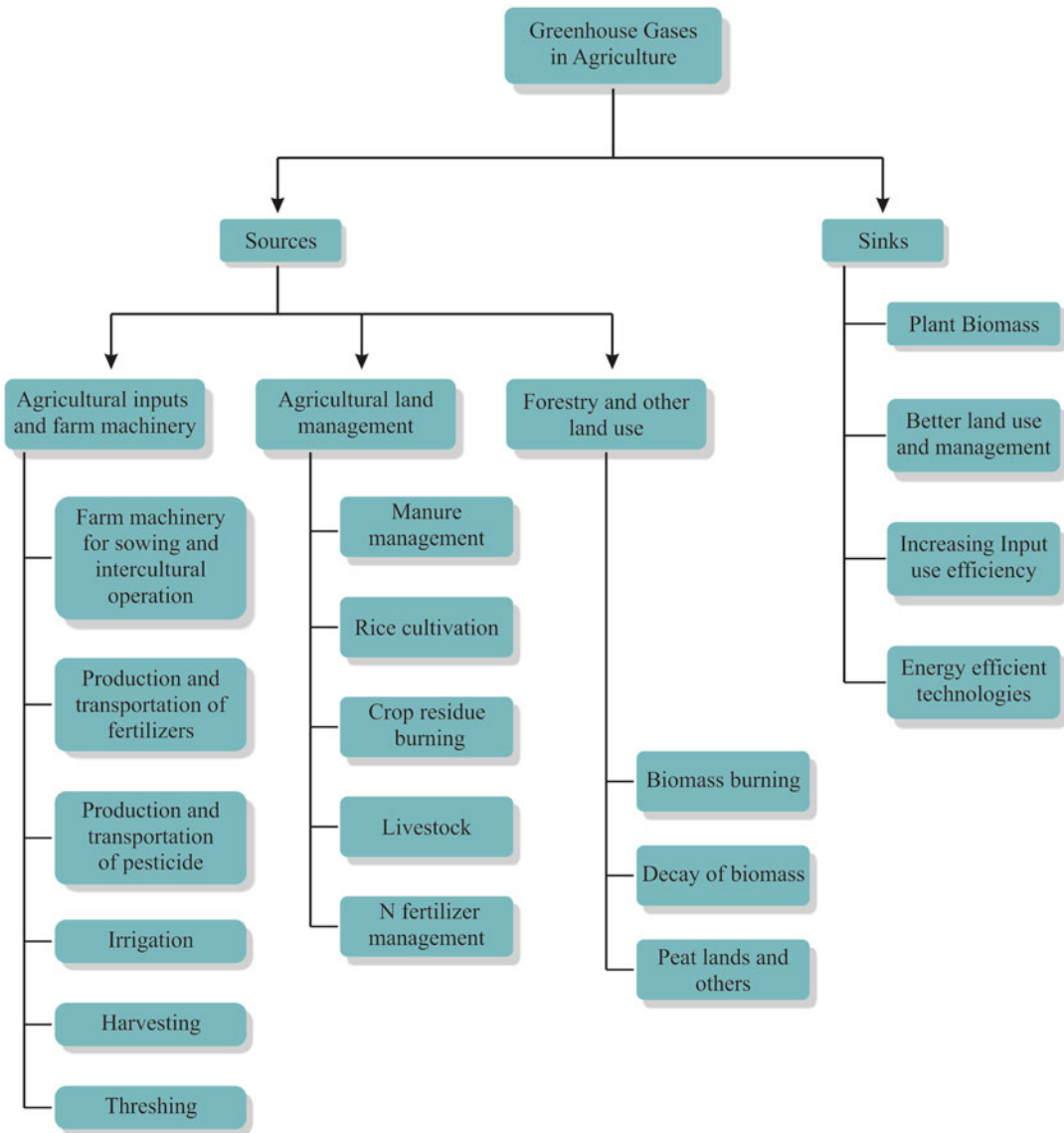


**Fig. 3.1** Comparing AR<sub>4</sub> and AR<sub>5</sub> the sectoral distribution of GHG emissions showing the percentage of emission with respect to the total. AR<sub>4</sub> represent emission level at 2004 and AR<sub>5</sub> 2010

emissions/sequestration from land under continuous use. The new category land use, land-use change, and forestry (LULUCF) was thus created (Paustian et al. 2006). In the 2006 IPCC guidelines, the categories have been altered and amalgamated, with only four sectors to which GHG emissions are now attributed. The agriculture and LULUCF sectors were combined to produce the sector agriculture, forestry, and other land use (AFOLU) (Crosson et al. 2011).

Figure 3.2 gives a schematic presentation of emission by sources and removals by sinks in agriculture. And their detailed discussion is given in following section.

In agriculture the non-CO<sub>2</sub> sources (CH<sub>4</sub> and N<sub>2</sub>O) are reported as anthropogenic GHG emissions, however. The CO<sub>2</sub> emitted is considered neutral, being associated to annual cycles of carbon fixation and oxidation through photosynthesis (IPCC 2007). Soil respiration is roughly



**Fig. 3.2** Schematic presentation of sources and sinks of GHGs in agriculture, forestry, and other land use (AFOLU)

balanced by the net uptake of CO<sub>2</sub> through plant photosynthesis. Carbon inputs to the soil are determined by the quantity, quality, and distribution of primary productivity. The organic matter decomposition and microbial respiration are influenced by soil physicochemical and biological soil properties controlling the activity of soil microorganisms and fauna. Also there is growing consensus on soil respiration and hence CO<sub>2</sub> evolution is higher when any organic material is added to soil. Similarly soils with higher soil organic carbon (SOC) content emit more CO<sub>2</sub> than soil with low SOC, thereby increasing concentration of CO<sub>2</sub> in the atmosphere. On the other hand, higher concentrations of atmospheric CO<sub>2</sub> also will stimulate the growth of most plants, especially C<sub>3</sub> agricultural crops. Increased productivity can supply more plant residues to the soil, possibly increasing storage of SOM. But, higher level of atmospheric CO<sub>2</sub> is also coupled with temperature rise which would have both positive and negative effects on plant productivity. If the productivity decreases it would have a negative effect on soil carbon storage. Thus, accounting CO<sub>2</sub> emission and removal in agriculture should be considered in creating GHG inventory from agriculture. Further, the link between agriculture and climate change must be assessed and presented accurately and consistently. Flaws in the assessment of agriculture's contribution will lead to dispute, failure to trust the science, and, consequently, failure to act. Global recognition of the extent of agriculture's contribution to GHG emissions is required, as is quantification of how its contribution compares to that of other emission sources.

### 3.2.1 Rice Cultivation

The four decades since 1961 have seen an increase in area, production, and productivity of rice of 31.2, 174.9, and 109.7 %, respectively. The acreage under rice cultivation in the world is estimated at about 151.54 million hectares, mostly planted in wet monsoon or irrigated systems by flooding and puddling fields. These rice fields are a major source of emission of GHGs like CH<sub>4</sub>

and N<sub>2</sub>O. From 1961 to 2010, global emissions increased with average annual growth rates of 0.4 %/year (FAOSTAT 2013) from 0.37 to 0.52 GtCO<sub>2</sub> eq/year. The growth in global emissions has slowed in recent decades, consistent with the trends in rice-cultivated area. The developing countries are major producers of rice and also the largest share of methane emission approximately 94 % came from them. Researchers have attempted to model and estimate GHG emissions from rice fields under varying growing conditions. However, there are uncertainties in the estimation of GHG from rice fields due to diverse soil and climatic conditions and crop management practices. Flooded paddy soils have a high potential to produce CH<sub>4</sub>, but part of produced CH<sub>4</sub> is consumed by CH<sub>4</sub> oxidizing bacteria, or methanotrophs. It is known that microbial-mediated CH<sub>4</sub> oxidation, in particular aerobic CH<sub>4</sub> oxidation, ubiquitously occurs in soil and aquatic environment, where it modulates CH<sub>4</sub> emission. In rice fields, it is possible that a part of produced CH<sub>4</sub> in anaerobic soil layer is oxidized in aerobic layers such as surface soil-water interface and the rhizosphere of rice plants, and the net emission will be positive or negative depending on the relative magnitudes of methanogenesis and methanotrophy, respectively; the emission pathways of CH<sub>4</sub> which are accumulated in flooded paddy soils are diffusion into the flood water, loss through ebullition, and transport through the aerenchyma system of rice plants. Some promising mitigation options are (1) system of rice intensification (SRI), (2) water management, (3) adding organic material along with inorganic fertilizers, (4) reducing tillage operations before sowing, and (5) selecting suitable variety which emit less CH<sub>4</sub>, and there is no reduction in yield.

### 3.2.2 Livestock Production

Livestock contribute both directly and indirectly to climate change through the emissions of GHGs such as carbon dioxide, methane, and nitrous oxide. Globally, the sector contributes 18 % (7.1 billion tonnes CO<sub>2</sub> equivalent) of global GHG emissions. Although it accounts for only 9 % of

global CO<sub>2</sub>, it generates 65 % of human-related nitrous oxide (N<sub>2</sub>O) and 35 % of methane (CH<sub>4</sub>), which has 310 times and 23 times the global-warming potential (GWP) of CO<sub>2</sub>, respectively.

There are two sources of GHG emissions from livestock: (a) From the digestive process, methane is produced in herbivores as a by-product of “enteric fermentation,” a digestive process of enzymatic degradation elaborated by symbiotic microbes inhabiting in rumen medium in which carbohydrates are broken down into simple molecules for absorption into the bloodstream. (b) From animal wastes, animal wastes contain organic compounds such as carbohydrates and proteins. During the decomposition of livestock wastes under moist, oxygen-free (anaerobic) environments, the anaerobic bacteria transform the carbon skeleton to methane. Animal wastes also contain nitrogen in the form of various complex compounds. The microbial processes of nitrification and denitrification of animal waste form nitrous oxide, which is emitted to the atmosphere.

The major global-warming potential (GWP) of livestock production worldwide comes from the natural life processes of the animals. Methane production appears to be a major issue although it presently contributes only 18 % of the overall warming. It is accumulating at a faster rate and is apparently responsible for a small proportion of the depletion of the protective ozone layer. Methane arises largely from natural anaerobic ecosystems, rice/paddy field, and fermentative digestion in ruminant animal (Sejian et al. 2011). In fact, CH<sub>4</sub> considered to be the largest potential contributor to the global-warming phenomenon is an important component of GHG in the atmosphere and is associated with animal husbandry. Much of the global GHG emissions currently arises from enteric fermentation and manure from grazing animals and traditional small-scale mixed farming in developing countries. The development of management strategies to mitigate CH<sub>4</sub> emissions from ruminant livestock is possible and desirable. Not only can the enhanced utilization of dietary “C” improve

energy utilization and feed efficiency, hence animal productivity, but a decrease in CH<sub>4</sub> emissions can also reduce the contribution of ruminant livestock to the global CH<sub>4</sub> inventory.

### 3.2.2.1 Enteric Methane Emission from Livestock

Livestock are produced throughout the world and are an important agricultural product in virtually every country. CH<sub>4</sub> is emitted as a by-product of the normal livestock digestive process, in which microbes resident in the animal’s digestive system ferment the feed consumed by the animal. This fermentation process, also known as enteric fermentation, produces CH<sub>4</sub> as a by-product. The CH<sub>4</sub> is then eructated or exhaled by the animal. Within livestock, ruminant livestock (cattle, buffalo, sheep, and goats) are the primary source of emissions. Other livestock (swine and horses) are of lesser importance in nearly all countries. The number of animals and the type and amount of feed consumed are the primary drivers affecting emissions. Consequently, improvements in management practices and changes in demand for livestock products (mainly meat and dairy products) will affect future CH<sub>4</sub> emissions (Sejian et al. 2012).

Among the livestock, cattle population contributes most towards enteric CH<sub>4</sub> production (Johnson and Johnson 1995). Enteric fermentation emissions for cattle are estimated by multiplying the emission factor for each species by the relevant cattle populations. The emission factors are an estimate of the amount of CH<sub>4</sub> produced (kg) per animal and are based on animal and feed characteristic data, average energy requirement of the animal, the average feed intake to satisfy the energy requirements, and the quality of the feed consumed. The district- or country-level emission from enteric fermentation is computed as a product of the livestock population under each category and its emission coefficient (Chhabra et al. 2009). The emission coefficients for CH<sub>4</sub> emissions from enteric fermentation are country specific, and these coefficients should conform to IPCC guidelines (IPCC 2007).

### 3.2.2.2 GHG Emission from Livestock Manure

Animal manures contain organic compounds such as carbohydrates and proteins. These relatively complex compounds are broken down naturally by bacteria. In the presence of oxygen, the action of aerobic bacteria results in the carbon being converted to carbon dioxide, and, in the absence of oxygen, anaerobic bacteria transform carbon to methane. When livestock are in fields and their manure ends up being spread thinly on the ground, aerobic decomposition usually predominates. However, with modern intensive livestock practices, where animals are often housed or kept in confined spaces for at least part of the year, manure concentrations will be higher, and manure will often be stored in tanks or lagoons where anaerobic conditions generally predominate and methane will be evolved. Methane emissions from manure depend on (1) the quantity of manure produced, which depends on number of animals, feed intake, and digestibility; (2) the methane-producing potential of the manure which varies by animal type and the quality of the feed consumed, e.g., slurry from swine emits more GHG than does slurry from cattle (Dinuccio et al. 2008); the way the manure is managed (e.g., whether it is stored as liquid or spread as solid); the climate as the warmer the climate the more biological activity takes place and the greater the potential for methane evolution and temperature and duration of storage as long-term storage at high temperature results in higher methane emissions.

Management decisions about manure disposal and storage affect emissions of  $\text{CH}_4$  and  $\text{N}_2\text{O}$ , which are formed in decomposing manures as a by-product of methanogenesis and nitrification/denitrification, respectively. Livestock manure is principally composed of organic material. When this organic material decomposes under anaerobic environment, methanogenic bacteria produce methane. When manure is stored or treated as a liquid (e.g., in lagoons, ponds, tanks, or pits), it tends to decompose anaerobically and produce a significant quantity of methane. When manure is handled as solid (e.g., in stacks or pits) or deposited on pastures and rangelands, it tends to

decompose aerobically and little or no methane is produced. Furthermore, volatilization losses of  $\text{NH}_3$  and  $\text{NO}_x$  from manure management systems and soils lead to indirect GHG emissions. There are three potential sources of  $\text{N}_2\text{O}$  emissions related to livestock production (Swamy and Bhattacharya 2011). These are (a) animals themselves, (b) animal wastes during storage and treatment, and (c) dung and urine deposited by free-range grazing animals. Direct emission from animals is not reported. Only liquid systems (anaerobic lagoons and other liquid systems) qualify under manure management. Emissions from stable manure applied to agricultural soil (e.g., daily spread), from dung and urine deposited by range grazing animals, and from solid storage and dry lot are considered to be emissions from agricultural soil. Although  $\text{CH}_4$  and  $\text{N}_2\text{O}$  emissions from manure management are minor, manure itself is an important contributor to emissions because it is either applied on cropland as organic fertilizer or directly deposited by grazing animals on pasture. Global emissions from manure, as either organic fertilizer on cropland or manure deposited on pasture, grew between 1961 and 2010 from 0.57 to 0.99  $\text{GtCO}_2$  eq/year. Emissions grew by 1.1 %/year on average (IPCC AR5). Also the GHG emissions are more from manure deposited on soil surface in pasture lands or the backyard of farm land compared to when applied to agricultural land before sowing.

## 3.3 Agricultural Soils

Direct and indirect emissions from agricultural soil are determined by a multitude of factors such as the rate of fertilizer and organic manure application, yield, and area under cultivation. Direct emission sources include N fertilizers, crop residues, and mineralization process of soil organic matter. Indirect sources comprise leaching, runoff, and atmospheric deposition.  $\text{N}_2\text{O}$  emitted from the soil represents some 50 % of the total agricultural emissions. Even when it is not being cultivated, the soil naturally releases GHGs.  $\text{N}_2\text{O}$  is generated as a by-product of microbial activities that convert ammonium into nitrate

(nitrification) or nitrate into nitrogen gas  $N_2$  (denitrification). Both processes are influenced and controlled by environmental conditions. They are independent of the origin of N, whether from organic or mineral fertilizers or soil organic matter. Emissions increase with agricultural activity, partly as a result of N input from manure, mineral fertilizers, or from symbiotic N fixation in legumes. Globally, use of synthetic fertilizers in agriculture has increased more than agricultural production, and emissions from synthetic N fertilizers are increasing more than ninefold, from 0.07 to 0.68 GtCO<sub>2</sub> eq/year from 1951 to 2010 (Tubiello et al. 2013). Considering current trends, synthetic fertilizers will become a larger source of emissions than manure deposited on pasture in less than 10 years and the second largest of all agricultural emission categories after enteric fermentation. Globally, agricultural sources contribute to 4–6 Tg N/year through N<sub>2</sub>O, including both direct and indirect emissions (Sharma et al. 2011).

The Intergovernmental Panel on Climate Change (IPCC) assumes a default value of 1 % of N content of the substrate, emitted as N<sub>2</sub>O. As these emissions are the consequences of natural processes, they are difficult to control. The best possible approach is to increase nitrogen use efficiency. In addition, emission during fertilizer manufacturing can be reduced with new cleaning technology which can enable N<sub>2</sub>O emission reduction by about 70–90 % (Kongshaug 1998).

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### 3.4 Burning of Agricultural Residues in Field

The contribution of crop residue burning is the lowest 0.5 % of the total agricultural emissions among different sources of GHG emission in the agriculture sector. In developing countries agricultural wastes are burnt in the field to clear the remaining straw and stubble after harvest and to prepare the field for the next cropping cycle. Farmers prefer crop residue burning as a quick and labor-saving process to dispose of the crop residues of rice, wheat, maize, and sugarcane. Emissions of CO<sub>2</sub> during burning of crop resi-

dues are considered neutral, as it is reabsorbed during the next growing season. However, biomass burning is one of the significant sources of atmospheric aerosols and trace gas emissions, which has a major impact on human health. In addition to aerosol particles, biomass burning due to forest fires and crop residue burning are considered a major source of carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), methane (CH<sub>4</sub>), volatile organic compounds (VOC), nitrogen oxides, and halogen compounds. Carbon monoxide is a chemically active gas in the troposphere influencing the abundance of O<sub>3</sub> and the oxidizing capacity (OH) of the troposphere. Thus, an increase in concentration of CO, VOC, and NO<sub>x</sub> also increases concentration of GHGs in the atmosphere. Biomass burning is one of the main causes for dense brown clouds. Smoke particles from biomass burning have direct radiative impact by scattering and absorbing shortwave radiation and indirect radiative impact by serving as cloud-condensation nuclei (CCN) and changing the cloud microphysical and optical properties.

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### 3.5 Forestry and Other Land Use (FOLU) Changes

This section of agriculture sector encompasses anthropogenic emission from deforestation, cultivation of organic soils, peatland drainage for cultivation, forest fires, etc. Emissions from cultivation of organic soils have become important because when peatlands are drained and degraded there is change in absolute carbon stocks. The continued expansion of farmland has a major environmental impact. It decreases biodiversity through destruction of ecologically valuable natural environments, such as forests and natural grasslands. In addition, deforestation and depletion of the humus releases large quantities of CO<sub>2</sub> from the carbon bound in the trees and the soil organic matter (SOM). Furthermore, deforestation has an immediate impact on the natural water cycle, resulting in a greater likelihood of flooding or drought. Some 24 % of the total global GHG emissions can be currently attributed to



agriculture. About 12 % of these are due to change in land use and, with extended agricultural production, this percentage would rise considerably (FAOSTAT 2013). Further extension of the agricultural land area, therefore, should be kept to the minimum. Changes in land use have negatively affected the net ability of ecosystems to sequester C from the atmosphere. For instance, the C-rich grasslands and forests in temperate zones have been replaced by crops with much lower capacity to sequester C. However, the estimates indicate that the FOLU sector is a net sink. It helps in sequestering CO<sub>2</sub> annually offsetting FOLU emissions. The sink capacity of FOLU is due to afforestation and forest protection.

### 3.6 Agricultural Inputs and Farm Machinery

#### 3.6.1 Fuel and Electricity

Use of fossil fuels in agriculture results in CO<sub>2</sub> emissions, and there are additional emissions associated with production and delivery of fuels to the farm. Carbon emissions attributed to fossil fuels are estimated using existing C coefficients, higher heating values, fuel chemistry, and the energy consumed during production and transport of the fuels. Nontraditional fuels sometimes used in processing agricultural materials include scrap tires and biomass. The CO<sub>2</sub> emission attributed to electricity consumption is based on the fuels used in power generation.

#### 3.6.2 Fertilizers and Agricultural Lime

The production of fertilizers demands much energy and generates considerable GHG emissions. Kongshaug (1998) estimates that fertilizer production consumes approximately 1.2 % of the world's energy and is responsible for approximately 1.2 % of the total GHG emissions. The fertilizer industry deals primarily with supplying N, P, and K, although chemical fertilizers are used to supply 13 essential plant nutrients. This

analysis includes the three primary nutrients and agricultural lime (CaCO<sub>3</sub>) in the form of crushed limestone. Carbon dioxide emissions result from the energy required for production of fertilizers plus the energy required for their transport and application. The energy required per tonne of N and phosphate (P<sub>2</sub>O<sub>5</sub>) varies considerably with the form in which the nutrient is supplied. Carbon emissions from fossil fuels used in the production of fertilizers include emissions from mineral extraction and fertilizer manufacture. Postproduction emissions can include those from packaging, transportation, and field application of fertilizers. Energy is also used during fertilizer application using farm machinery, thus the greater the fertilizer use, the greater are the emissions. Carbon emissions from agricultural lime are calculated from the fuel used for mining limestone and for grinding the stone into a usable product. Energy used in the transportation of fertilizers and lime should be included in estimating the total energy budget.

#### 3.6.3 Pesticides

Modern pesticides are almost entirely produced from crude petroleum or natural gas products. The total energy input is thus both the material used as feedstock and the direct energy inputs. Carbon dioxide emissions from production of pesticides consist of both these contributions to manufacture the active ingredient. Postproduction emissions include those from formulation of the active ingredients into emulsifiable oils, wettable powders, or granules and those from packaging, transportation, and application of the pesticide formulation. Carbon dioxide emissions from pesticide use are estimated for specific pesticide classes by calculating average values of energy input for the production and application of individual pesticides.

#### 3.6.4 Irrigation

The on-farm wells, on-farm surface reservoirs, and off-farm surface reservoirs are the major

sources of irrigation water. Fossil fuels used to power pumps, which distribute irrigation water, were calculated using energy expenses for on-farm pumping and energy price estimates. The energy use and C emissions from pumping water were applied to both on-farm wells and off-farm surface reservoirs. It is assumed that the average energy and CO<sub>2</sub> cost of pumping water is the same per ha-m of water for the two sources. The energy cost of collecting and distributing on-farm surface water, powered primarily by gravitational forces, was considered to be negligible.

### 3.6.5 Harvesting and Threshing

Energy and CO<sub>2</sub> emissions during harvesting and threshing of agricultural produce are also important. The greater the productivity, the greater are the energy and emissions required for harvesting and threshing.

### 3.6.6 Farm Machinery

Energy and CO<sub>2</sub> emissions associated with different tillage practices are a consequence of the fuel used by farm machines and the energy consumed in manufacture, transportation, and repair of the machines. While CO<sub>2</sub> emissions associated with the application of fertilizers and pesticides were calculated along with other farm operations, they do not occur on all fields and in all years, as do other farm operations. Therefore, CO<sub>2</sub> emissions from the application of fertilizers and pesticides are weighted by their extent of application.

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## 3.7 Key Mitigation Options in Agriculture, Forestry, and Other Land Use

To reduce the impact of climate change mitigation and adaptation are the two key options available. Mitigation options are focused at reducing the emissions of GHGs from agriculture sector and at the same time meeting the demands of food production by the growing population.

Mitigation activities are traditionally employed as natural resources conservation measures, but they generally serve the dual purposes of reducing the emission of GHG from anthropogenic sources and enhancing carbon “sink.” Forestry sector holds the key to the success of mitigation efforts and has great potential to sequester carbon through reduced emissions from deforestation and degradation (REDD), afforestation and reforestation, and forest management (Lenka et al. 2013). A variety of options exists for mitigation of GHG emissions in agriculture. The most prominent options are improved crop and grazing land management (e.g., improved agronomic practices, nutrient use, tillage, and residue management), increasing partial factor productivity and input use efficiency, restoration of organic soils that are drained for crop production, and restoration of degraded lands. Lower but still significant mitigation is possible with improved water and rice management; set-asides, land-use change (e.g., conversion of cropland to grassland), and agroforestry or other perennial planting in agricultural lands; as well as improved livestock and manure management. Many mitigation opportunities use current technologies and can be implemented immediately, but technological development will be a key driver ensuring the efficacy of additional mitigation measures in the future. Also the suitability and recommendation of mitigation technology is site specific and need based. There are few constraints and challenges in transferring of these mitigation technologies to a farmer’s field. There is a need to address the issues and constraints and devise ways in achieving the large-scale adoption of climate-friendly agricultural practices. The established linkage of GHG emission with climate change has led to international negotiations and the recognition of carbon (C) as a tradable commodity. Agriculture practices with low C footprint can be a triple win in form of enhanced adaptation, increased mitigation, and stability in the food security and sustainability in the country. The imposition of a CO<sub>2</sub> tax on agricultural activity would result in a reduction of agricultural production, particularly for GHG-intensive commodities. In contrast, if farmers were rewarded for carbon sequestration

activities (specifically agroforestry), this would lead to intensification, as more inputs are applied to the land remaining in agriculture. Emissions per unit of agricultural land would increase but would decline per unit of output. They are also supportive of arguments made by others that if global agriculture is to meet the needs of an expanding world population while simultaneously contributing to mitigation of GHG emissions, changes in the structure of production and intensification will be required (Blandford et al. 2014). Carbon offset program can be successful in agriculture sector only if the carbon credits to be traded are in a bulk quantity, easily measurable, and there are buyers to buy the credits. Thus, measures at the government level to effectively integrate farmers into carbon trading processes are needed. For example, if conservation agriculture is considered as a tradable activity, then the scale of adoption should be sizable so that a pool of credits is generated. Similarly, degraded land restoration measures and soil health improvement programs can be brought into the C trading network.

### 3.8 Conclusion

Management of agricultural land, land-use change, and forestry has a profound influence on atmospheric GHG concentration. In the agriculture sector, besides the CO<sub>2</sub> emissions due to burning of crop and animal waste, the world's livestock population and rice fields are significant contributors to CH<sub>4</sub> emissions. The two broad anthropogenic sources of GHG emission from agriculture are the energy use in agriculture (manufacture and use of agricultural inputs and farm machinery) and the management of agricultural land. An understanding of GHG emissions by sources and removal by sinks in agriculture is important to take appropriate mitigation and adaptation strategies and to estimate and create inventory of GHGs. Within the scientific community there is increasing recognition that agriculture in general, and livestock production in particular, contributes significantly to GHG

emissions. As a result, the global agricultural community is committed to reducing emissions to safeguard the environment; however, it must simultaneously meet the demands of a growing human population and their increasing requirements for food high in quality and quantity. There is a need to improve the efficiency of agricultural production if we are to meet global food supply demands and decrease agriculture's impact on climate change.

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