CHAPTER 2

SCIENTIFIC BACKGROUND

2.1 Greenhouse Effect and Greenhouse Gases

The greenhouse effect is the heating of the Earth's surface due to the presence of greenhouse gases. Shorter-wavelength solar radiation from the sun passes through Earth's atmosphere, and there is absorbed by the surface of the Earth, causing it to warm. Some of these longer wavelengths are absorbed by greenhouse gases in the atmosphere before they are lost to space. The absorption of this long-wave radiant energy warms the atmosphere. Little of this long wave radiation escapes back into space however, the radiation cannot pass through the greenhouse gases in the atmosphere. The greenhouse gases selectively transmit the infrared waves, trapping some and allowing some to pass through into space.

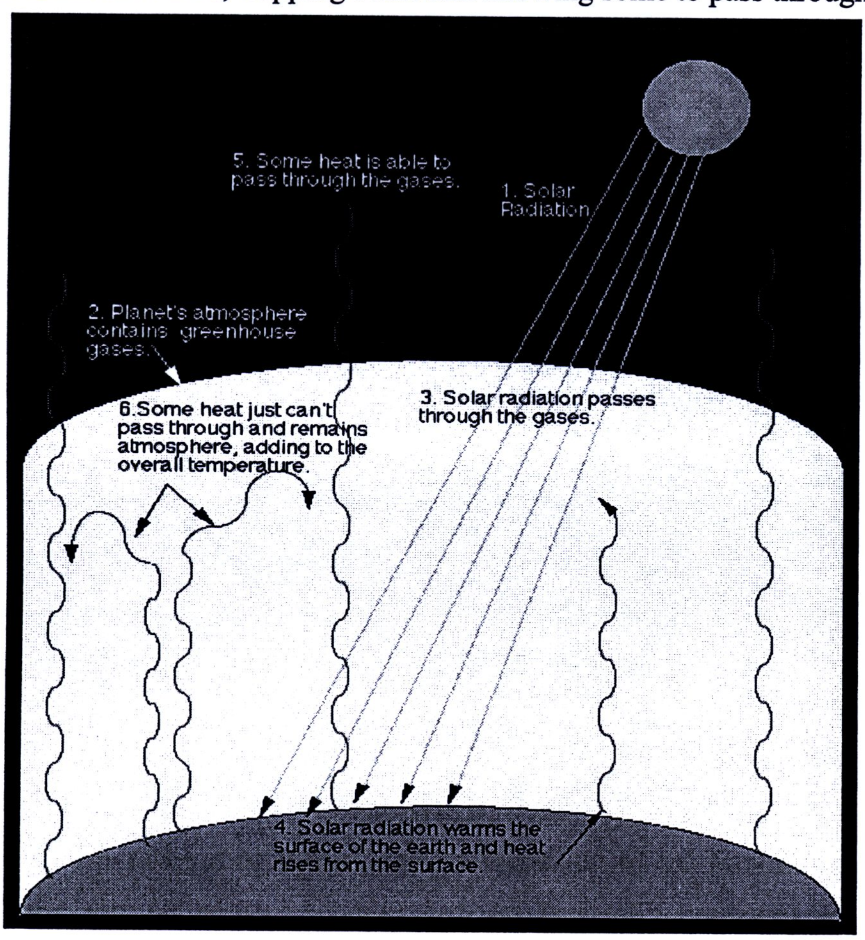


Figure 2.1 The process of global warming,

Source:www.eecs.umich.edu/mathscience/funexperiments/agesubject/lessons/images/diagrampage.html

Greenhouse gases (GHGs) are gaseous components of the atmosphere that contribute to the greenhouse effect. Some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Human activity raises levels of greenhouse gases in atmosphere. Some of the main sources of greenhouse gases due to human activity include burning of fossil fuels and deforestation leading to higher carbon dioxide concentrations, livestock and paddy rice farming, land use and wetland changes and covered vented landfill emissions leading to higher methane atmospheric concentrations. The global annual emission of anthropogenic GHGs and the share of different emission source in 2004 show in figure 2.2. Current contributions of GHGs from agriculture are 13.5% of anthropogenic greenhouse gases, that the important GHGs emitted are methane and nitrous oxide.

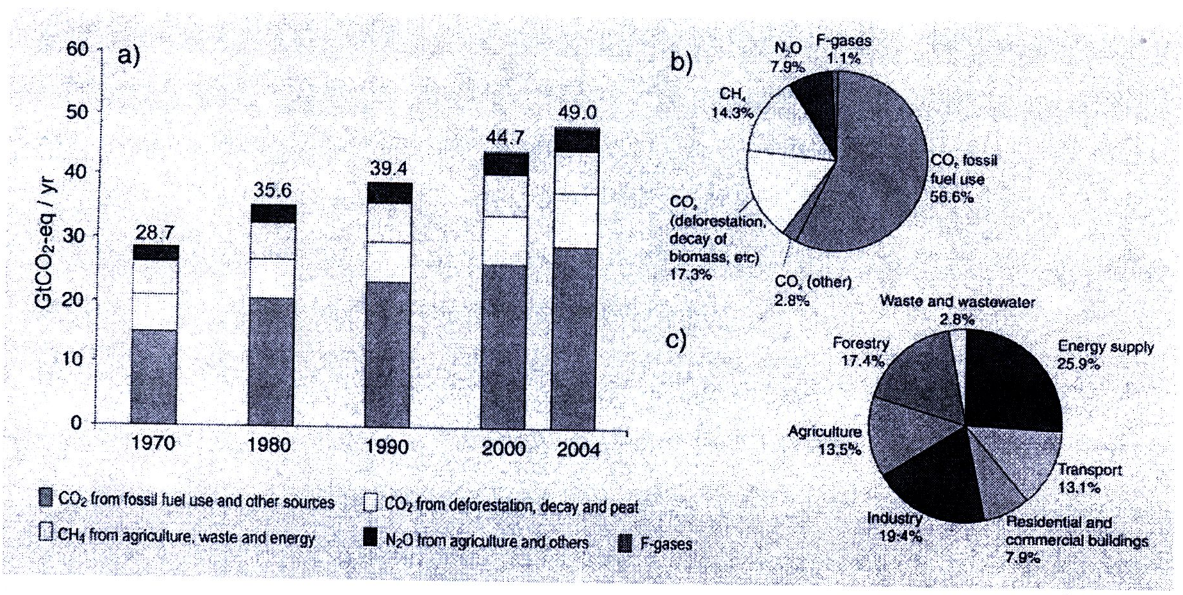


Figure 2.2 Global annual emission of anthropogenic greenhouse gas from 1970 to 2004 and share of GHGs emission in 2004 Source: (IPCC, 2007)

Carbon Dioxide (CO_2) is a colorless, odorless non-flammable gas and is the most prominent greenhouse gas in Earth's atmosphere. It is recycled through the atmosphere by photosynthesis. The amount of carbon dioxide taken out of the atmosphere by plants is almost balanced with the amount put back into the atmosphere by respiration and decay. The changes as a result of human activities an example, deforestation can have a large impact on this delicate balance. CO_2 has a variable atmospheric lifetime (approximately

200-450 years for small perturbations). Carbon dioxide is defined to have a GWP of 1 over all time periods when compare to other GHGs.

The atmospheric mixing ratio of CO_2 has increased globally by about 100 ppm (36%) over the last 250 years, confirmed by a wide range of direct and indirect measurements. In AD 1000–1750 (pre-industrial era), the atmospheric CO_2 increased from 275 to 285 ppm and rise up to 379 ppm in 2005 (Solomon, 2007). The average rate of increase in CO_2 determined by the direct instrumental measurements over the period 1960 to 2005 is 1.4 ppm per year.

Methane (CH_4) is a colorless, odorless and flammable gas. Most of the methane in the Earth's atmosphere comes from natural and anthropogenic sources. Biological processes and rice paddies are one of the main sources. CH_4 is formed when plants decay and where there is very little oxygen. Bacteria that breakdown organic matter in wetlands and bacteria that are found in cows, sheep, goats, buffalo, termites, and camels produce methane naturally. The importance of methane in the greenhouse effect is its warming effect. Methane has an atmospheric lifetime of 12 ± 3 years and a GWP of 62 over 20 years, 21 over 100 years and 7 over 500 years (IPCC 1996). The decrease in GWP associated with longer times is associated with the fact that the methane is degraded to water and CO_2 by chemical reactions in the atmosphere.

Methane concentration in the atmosphere has more than doubled during the last 200 years. In 2005, the global average abundance of CH_4 measured at the network of 40 surface air flask sampling sites operated by NOAA/GMD in both hemispheres was 1,774.62 ± 1.22 ppb (Solomon, 2007). The atmospheric abundance of CH_4 has increased by about a factor of 2.5 since the pre-industrial era as evidenced by measurement of CH_4 in air extracted from ice cores and firn (IPCC, 2001).

Nitrous oxide (N_2O) under room conditions is a colorless non-flammable gas with a pleasant slightly sweet odor. This gas is released naturally from oceans and by bacteria in soils. The source of nitrous oxide emit into the atmosphere by using nitrogen based fertilizers, disposing of human and animal waste in sewage treatment plants, automobile exhaust. Nitrous oxide has an atmospheric lifetime of 120 years and a GWP of 296 over 100 years (IPCC, 2001).

Atmospheric concentration of N_2O has been increasing over the last few decades at an average rate of about 0.2% per year. IPCC reported that the globally averaged surface abundance of N_2O was 314 ppb in 1998. Since 1998, atmospheric N_2O levels have steadily raised to 319 ± 0.12 ppb in 2005. Natural nitrous oxide sources are the oceans, the atmosphere, tropical soil and temperate soils. The anthropogenic nitrous oxide sources are agricultural soils, biomass burning, industry, livestock and feed and transport. Agricultural soils dominate man-made nitrous oxide emissions with synthetic fertilizer use. Widespread increase in the use of such nitrogen based fertilizers has been driven by the need for greater crop yields, and by more intensive farming practices. The large applications of fertilizer are combined with soil conditions favorable to denitrification, that the biological process to be produced and emitted N_2O to the atmosphere. Moreover, indirect sources of nitrous oxide remain poorly defined in most cases. There are several ways in which such indirect emissions occur. The most important of these is nitrous oxide emission arising from nitrogen leaching and run-off from agricultural soils. After fertilizer application or heavy rain, large amounts of nitrogen may leach from the soil into drainage ditches, streams, rivers and eventually estuaries.

Perfluorocarbons (PFCs) is a general term for any group of synthetic organic compounds that contain fluorine and carbon. HCFC-22 has an atmospheric lifetime of 12.1 years and a GWP (100) of 1,700.

Sulfur hexafluoride (SF_6) is colorless, odorless, non-toxic, and non-flammable gas. It is used by the electricity industry as an insulator for circuit breakers, switch gear and other electrical equipment. Sulfur hexafluoride has an atmospheric lifetime of 3,200 years and a GWP (100) of 22,000.

CFC-12 has an atmospheric lifetime of 100 years and a GWP (100) of 10,600. PFCs, HFCs and SF_6 are very effective absorbers of infrared radiation, so that even small amounts of these gases contribute significantly to the climate system.

2.2 Greenhouse gases emission from rice field

With an estimated global emission of non-CO_2 GHGs from agriculture in 2005 accounted for 5.1 to 6.1 GtCO2-eq/yr or 10-12% of total global anthropogenic emissions of greenhouse gases, CH_4 contributes 3.3 GtCO2-eq/yr and N_2O 2.8 GtCO2-eq/yr. Methane emission from rice production constitute 11% of total non-CO_2 emissions from agriculture in 2005 (Smith, 2007).

The rice fields are considered to be not only a principal source of atmospheric methane, but also one of N_2O emissions (Towprayoon et al., 2005; Ma et al., 2009; Xing et al., 2009). Rice fields are categorized by diverse environments such as irrigated rice, rainfed rice, continuously flooded rice, deepwater rice and upland rice. Sass (2002) concluded that irrigated rice has the highest CH_4 source strength. The unique environment for soil microorganisms occurs when flooding the rice field. The soils are maintained under waterlogged condition during the rice cultivation. Soil ecosystems in a flood rice field are roughly divided into oxic, facultative and anoxic zone. Methane was produced in paddy soil and emitted mainly through the aerenchymal system of the rice plants (Cicerone and Shetter, 1981; Seiler et al., 1984; Holzapfel-Pschorn and Seiler, 1986). The pathways of N2O emission from a paddy soil were investigated by Yan et al., 2000. They found that the main pathway of N_2O emission depends on the soil water status. N_2O emitted through rice plants in the presence of floodwater, but N_2O emitted through soil surface in the absence of floodwater.

2.2.1 Processes of CH_4 production in soil

Methane is produced as the terminal step of the anaerobic breakdown of organic matter in paddy soils. Methanogenic bacteria, naturally occurring in ruminant animals, wetlands, and rice fields compete with other microorganisms for simple carbon compounds such as acetate. They are relatively poor competitors only becoming active after oxidizing compounds such as nitrate and sulfate have been exhausted by other reducing organisms (Jakobsen, 1981). Thus, in flooded systems, methanogens are most active under highly reduced conditions with ample carbon sources.

The organic carbon transformation requires successive actions of four populations of micro-organisms that degrade complex molecules in simpler compounds (Figure 2.3):

- Hydrolysis of biological polymers into monomers (glucoses, fatty acids, amino acids) by an hydrolytic microflora that can be either aerobic, or facultative, or strictly anaerobic;

- Acidogenesis from monomeric compounds and intermediary compounds formed during fermentation (production of volatile fatty acids, organic acids, alcohols, H_2 and CO_2) by a fermentative;

- Acetogenesis from the previous metabolites by a syntrophic or homoacetogenic microflora; and

- Methanogenesis from the simple compounds that can be used by methanogens (in particular H_2 + CO_2 and acetate) which constitutes the last step of the methanogenic fermentation (Le Mer and Roger, 2001).

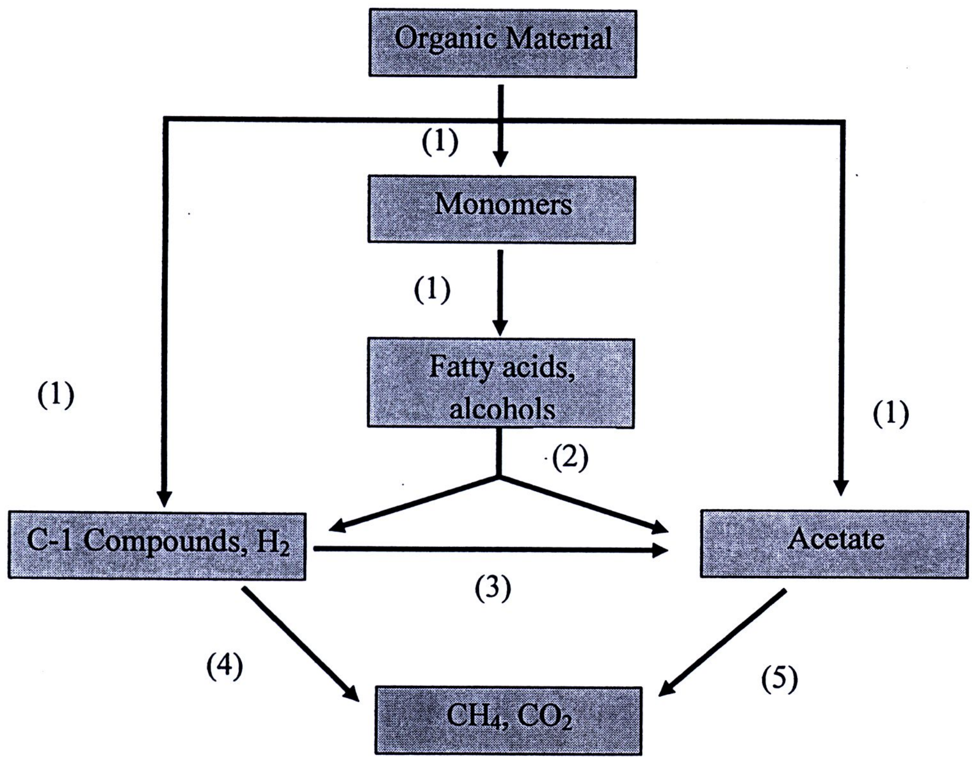


Figure 2.3 Overall scheme of anaerobic digestion process. Groups of bacteria involved: (1) Hydrolytic and fermentative bacteria, (2) Syntrophic bacteria, (3) Homoacetogens (4) Hydrogenotrophic methanogens, (5) Acetotrophic methanogens (Kimura, 2000).

The major pathways of CH_4 production in flooded soils are the reduction of CO_2 with H_2, with fatty acid or alcohols as hydrogen donor, and the transmethylation of acetic acid or methanol by methane-production bacteria. Carbon substrate and nutrient availability are also important factors (IPCC, 1996). Production of methane in anoxic rice soil is stimulated by the application of rice straw. The rice straw serves as substrate for a complex microbial community consisting of hydrolytic (cellulolytic), fermenting, homoacetogenic, synthrophic and methanogenic microorganisms. Hemicelluloses, cellulose, lignin and ash constitute 21-29%, 31-34%, 9-11% and 15-19% of the dry weight of rice straw, respectively (Watanabe et al., 1993). The major end products of the degradation process are methane and carbon dioxide.

Methanogens in rice soils

After flooding, a bud of microbial activity occurs. A flooded rice field is composed of five sites: floodwater, surface oxidized layer, reduced plow layer, oxidized subsoil, and rhizosphere of rice (Watanabe and Furusaka, 1980). Methanogenesis is a final degradation process of organic matter in reduced zone. Methanogens are strict anaerobes, and they are classified as members of the domain Archaea. Whitman et al. (2006) separated the order of methanogen into three orders using their kinds of energy substrates.

(1) Order Methanobacteriales, the energy substrate are H_2, formate or certain alcohols, and the electron acceptor is CO_2.

(2) Order Methanococcales, the energy substrate is one of a variety of methyl-containing C-1 compounds, and these compounds are disproportionate. Some molecules of the substrates are oxidized to CO2. The electron acceptors are the remaining methyl group, which are reduced directly to methane.

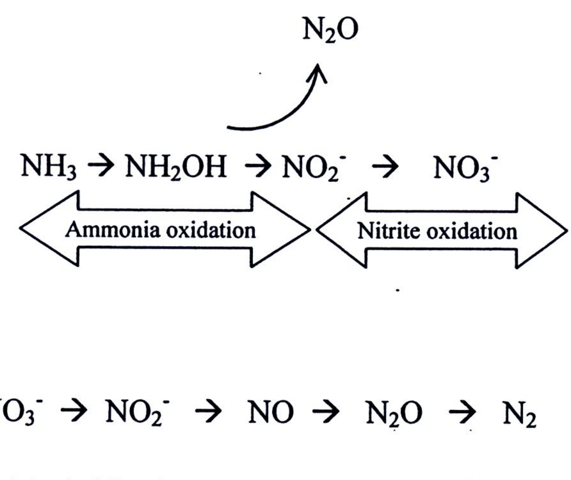
(3) Order Methanomicrobiales, the members of this group is limited to species of Methanosarcina and Methanosaeta that they can catabolize acetate. The methyl carbon of acetate is reduced to CH_4 and the carboxyl carbon is oxidized to CO_2 that called aceticlastic reaction. Usually, methanogenic activity increases sharply after flooding of rice fields, however the methanogens population survives in dry and aerobic conditions in paddy fields. Quantities of methanogen do not fluctuate significantly between fallow period and the rice cultivation period (Kimura, 2000; Mayer and Conrad, 1990). Watanabe et al. (2006) also found that the methanogenic archaeal community was stable throughout a year including the rice cultivation under flooded conditions and the wheat cultivation under upland conditions. In addition, the cluster analysis and principal component analysis suggested the effect of soil type to the community structures of methanogenic archaea. The rice field soils contain Rice Cluster I (RC-1) methanogens as a major population of methanogens (Ikenaga et al., 2004). Conrad et al. (2008) analyzed the community

composition by terminal restriction fragment length polymorphism and cloning/sequencing of the archaeal 16S rRNA gene and the mcrA gene coding for a subunit of the methyl coenzyme M reductase. They found that the type of rice cultivar affects the composition of the methanogenic community on the roots, and the type of methanogens colonizing rice roots has a potentially important impact on methane emission.

2.2.2 Processes of N_2O production in soil

Nitrous oxide (N_2O) is an important greenhouse gas that is predominantly emitted from soil environments especially from agriculture soil. N_2O is an intermediate product in the processes of nitrification and denitrification. In rice cultivation, rice fields are under flooded conditions, denitrification is the main process to produce N_2O (Kimura, 2000).

Nitrification is the microbial oxidation of NH_4^+ or NH_3 to NO_3^- via NO_2^-. Nitrous oxide is formed during NH_3 oxidation through chemical decomposition of intermediates between NH_4^+ and NO_2^- such as NH_2OH or NO_2^- itself. This is usually regarded as a special form of chemodenitrification (Chalk and Smith, 1983).



(a)

(b)

Figure 2.4 Outline of (a) nitrification pathway, (b) denitrification pathway (Wrage et.al, 2001)

In facultative-anaerobic condition, denitrification is the stepwise reduction of NO_3^- to N_2. In contrast to nitrification, N_2O is a regular intermediate of denitrification which can be released in high quantities in low-oxygen environment with sufficient NO_3^- and metabolizable organic carbon (Wrage et.al, 2001).

In sub-merged soils, nitrification proceeds very slowly because O_2 is an important regulator of nitrification. Therefore, nitrifiers are active only in the oxidized zone around plant roots and at the water sediment interface. Low land rice is cultivated under a wide variety of climate, soil and hydrological conditions. Continuous flooded rice fields are not a potent source of atmospheric N_2O because N_2O is further reduced to N_2 under the strong anaerobic conditions. But, in irrigated rice field, due to rapid drainage, the surface soil may remain aerobic from the dissolved oxygen through irrigation water may add O_2 to the surface soil. In such a situation, considerable amount of N_2O may be produced via nitrification as well as denitrification and emitted from soil subsequently (Ghosh et al., 2003).

2.3 Effect of rice cultivation practices

2.3.1 Rice straw management influence on methane emission from paddy fields

Field studies at the International Rice Research Institute in 1992 showed that soil and added organic matter were the sources for initial methane production (Neue et al., 1996). Addition of rice straw increased CH_4 emission in early growing season compared with mineral fertilizers (Figure 2.5). The difference in CH_4 emission rates between plots treated with urea and amended with rice straw decreased over time and became insignificant at the end of the growing season. The rice plant has an increasing impact towards the end of season because roots and root exudates appear to be the major carbon sources at ripening stage.

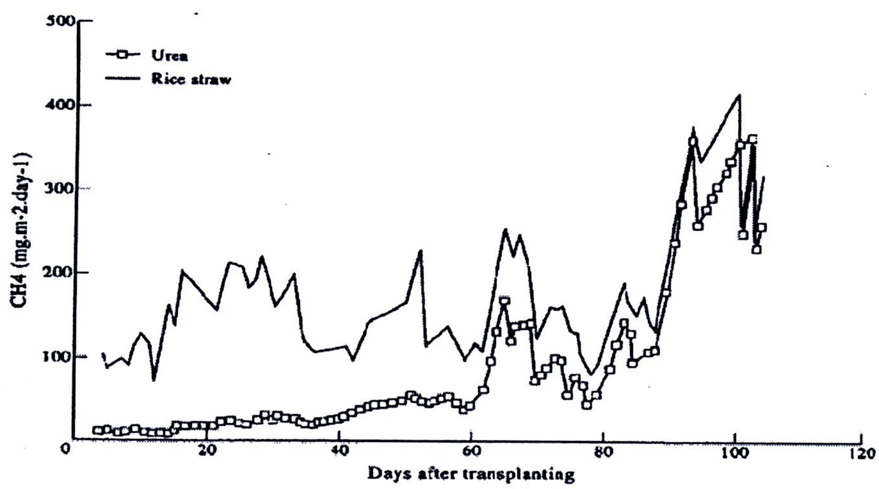


Figure 2.5 Methane emissions under two N sources. IRRI, 1992 wet season (Neue et al., 1996).

Analysis of six years of records of pot experiments from irrigated rice (Watanabe, 2005) confirmed the dependence of seasonal CH_4 emission on both temperature and rice straw application rate, which can be described by a single linear equation and total CH_4 emission were 2188 ± 132 and 917 ± 61 mg C pot^{-1} for treatments with and without rice straw application, respectively.

Liou et al. (2003) stated that stubble removed and straw burned treatment significantly reduced CH_4 emissions by approximately 56% compared to straw incorporated plot and they also reported that the seasonal methane fluxes in the first crop with rice stubble removed, rice straw burning and rice straw incorporated were 4.41, 3.79 and 5.27 g CH_4 m^{-2}, and the value were 32.8, 38.9 and 75.1 g CH_4 m^{-2} in the second crop season, respectively.

Agricultural burning of post-harvest residues is a common practice throughout the world. However, this practice has raised concern about air quality and human health in California. The studies of effect of incorporated rice straw compare with burned rice straw was established (Bossio et al., 1999; Fitzgerald, 1998). Redox values in the soil were found to be 50 mV lower in plots in which straw had been incorporated (-275 mV) than those in which it had been burned (-225 mV). Available organic matter was 1.5 times higher in straw incorporated than straw burned plots. A 5-fold increase in total CH_4 emissions over the rice growing season was observed in plots in which rice straw had been incorporated each fall for 4 year. Two water management, winter flood and non flood was trialed. The winter flooding promoted higher rates of rice straw decay compared to non-flooded treatments, despite cold winter temperature. The reasons for higher decay process under anaerobic condition are buffering of extremes in winter temperature due to the layer of water on the soil surface, more favorable nutrient availability to microbes due to a more neutral soil pH, or highly available soluble carbon and other nutrients leached from the straw in the winter.

Devevre and Horwath (2000) showed that anaerobes recycled fermentation waste products during the long-term incubation, resulting in a lower net residue-C mineralization in flooded systems compared to non-flooded conditions. As a result, they observed similar microbial production under flooded and non-flooded conditions even though anaerobes decomposed less straw-C than aerobes. These results indicate that a significant amount of decomposition occurred under flooded conditions, but because substrate use efficiency was higher, less straw-C was mineralized than in aerobic conditions. Flooding had a tendency to reduce C mineralization and enhance CH_4 production; however, with decreasing temperature CH_4 production became negligible.

2.3.2 Water management influence on methane emission from paddy fields

In general, field drainage is performed in order to protect the rice root from injury caused by extreme reduction conditions due to the decomposition of organic matter and to herbicide application. The field drainage as aeration to soil reduces methane concentration by oxidation process. The investigation of water drainage and rice straw treatment in rice fields showed the total methane emission was decreased by Eh control (Minamikawa and Sakai, 2006). Two methods of water management during rice growing period were continuous flooding and Eh control. For Eh control, drainage was carried out whenever the soil Eh decreased to -150 mV, and flooding was carried out whenever the soil Eh increased to 0 mV in 2003 and 100 mV in 2004. Two methods of rice straw treatment were application and removal in the preceding winters of all straw harvested. The total CH_4 emission was decreased by Eh control to 36% of continuous flooding on the 2-year average of this experiment. Although straw application hastened the decrease in soil Eh when compared with straw removal, it did not affect the total CH_4 emission. Result of aerobic decomposition of the straw during the fallow period (December–March) would have lowered the contribution to soil Eh and CH_4 emission. Rice grain and straw yields were not affected by the experimental factors. However, straw application also increased the number of panicles per hill, but did not affect brown rice yield.

The mitigation option as water drainage in irrigated rice field in Thailand (Towprayoon et al., 2005) presented the reduction of average methane emission per crop in the mid-season drainage and the multiple drainage with 27% and 35%, respectively, when compared to the local method. Finally, they suggested a mid-season drainage during the rice flowering period, with 3 days as a compromise between the need to reduce global warming and current socio-economic realities. Yagi et al., (1996) reported that CH_4 emission with intermittent irrigation decreased to 45% of continuous flooding. However, CH_4 was emitted during intermittent irrigation because the soil Eh at a depth of 5 cm. remained lower than -200 mV, which stimulates CH_4 emission.

2.3.3 Fertilizers influence on methane emission from paddy fields

The application of fertilizers is necessary in rice cultivation practice. Variations in types and quantities of fertilizers application has two-way effect with methane emission from rice field. Usually, the cultural practice uses chemical fertilizer for enhance rice growth. The studies of using ammonium sulfate application were shown in dimension of decreasing methane production in paddy soil. Minamikawa et al., (2005) reported that the methane emission decreasing with increases in ammonium sulfate application rate, caused by competition for substrates between sulfate-reducing bacteria and methanogens. Rath et al., (2002) studied the effect of ammonium thiosulphate application on production and emission of methane in a tropical rice soil. In ammonium thiosulphate-applied rice field plots, mean methane efflux decreased by about 38 and 60% at 45.6 and 60 kgN ha^{-1}, respectively, over that of no fertilizer application under continuous flooded conditions. In the laboratory-incubation experiments, application of ammonium thiosulphate at 30 or 60 gN g^{-1} soil under flooded conditions distinctly inhibited methane production by 45 and 73% over that of no fertilizer application, respectively.

The comparison study on effect of chemical fertilizer with differences in nitrogen fertilizers and rice varieties in Taiwan paddy field was made. The seasonal methane flux in the crop season with ammonium sulfate and potassium nitrate ranged from 2.48 to 2.78 and from 8.65 to 9.22 gCH4 m^{-2}; in the Indica rice cultivar and the values ranged 24.6–34.2 and 36.4–52.6 gCH4 m^{-2} in the Japonica rice cultivar, respectively (Liou et al., 2003). The ammonium sulfate treatment significantly reduced CH_4 emissions by 37–85% emissions compared to potassium nitrate plots.

However, in the area of using only chemical fertilizer, the sustainability of soil fertility should be considered in long-term effect to maintain healthy condition of the rice plant. The studied of the relation between methane emission, rice crop and N-fertilizers from irrigated rice fields founded the root porosity of rice plants varied significantly between rice varieties which was increased due to soil fertilization, chemical fertilizer plus manure, and was strongly correlated with methane emission (Singh et al., 1999). The methane emission was enhanced due to the presence of rice plants and varied significantly between varieties.

In a long-term different fertilization trial including non-fertilizer, chemical fertilizer, chemical fertilizer with manure, (Zheng et al., 2007), total methane and carbon dioxide production, and the total global warming potential (GWP) under chemical fertilization alone were significantly higher than under combined application of chemical and organic fertilizers. The long-term application of different fertilizers did not change the pathway of methanogenesis (Chidthaisong et al., 1999). The soil from the cow manure plot showed the highest rate of CH_4 formation, especially when supplemented with glucose or acetate. The rice straw plot soil showed significant CH_4 formation only when glucose was added. Methane formation in the chemical fertilizer alone and chemical fertilizer in combination with rice straw compost plots was low, even glucose or acetate was added.

2.4 Carbon cycle and carbon budget in agricultural soil

Carbon is the major chemical constituent of most organic matter. Carbon is stored on the Earth in the following major sinks. In the biosphere, carbon form in living and dead organisms as organic molecules. In the atmosphere found as the gas CO_2. Carbon in soil is in the form of organic matter. In the lithosphere, carbon form in fossil fuels and sedimentary rock deposits. Finally, the sink of carbon is the oceans as dissolved atmospheric CO_2 and sediment in form of calcium carbonate. Figure 2.6 shows the carbon cycle in the Earth.

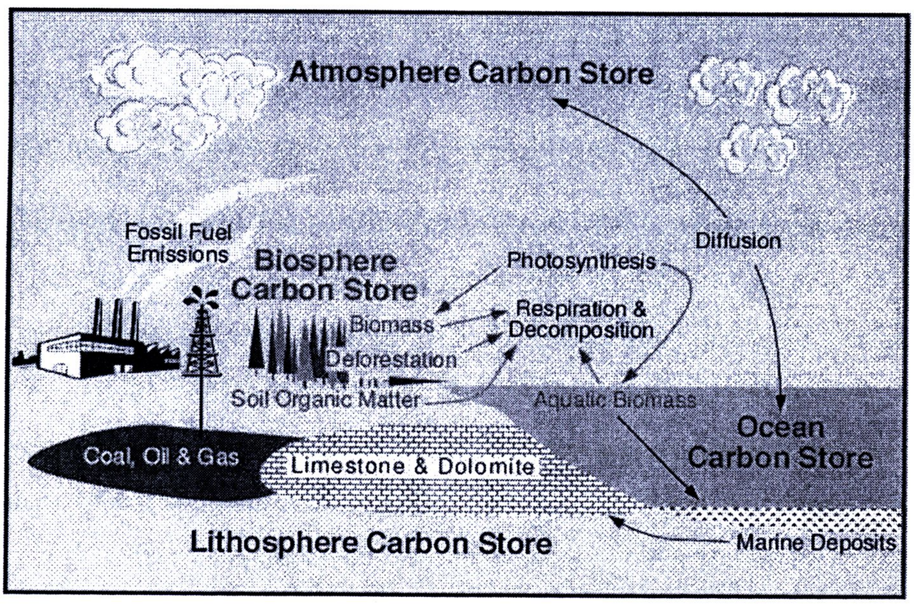


Figure 2.6 Carbon cycle of the Earth (Pidwirny, 2006)

Table 2.1 Estimated major stores of carbon on the Earth (Pidwirny, 2006).

Sink	Amount in Billions of Metric Tons
Atmosphere	578 (as of 1700) - 766 (as of 1999)
Soil Organic Matter	1500 to 1600
Ocean	38,000 to 40,000
Marine Sediments and Sedimentary Rocks	66,000,000 to 100,000,000
Terrestrial Plants	540 to 610
Fossil Fuel Deposits	4000

Carbon budget in agricultural soil

Photosynthesis is the main process which organisms use to chemically convert the CO_2 from atmosphere to carbon-based sugar molecules, with the addition of water and energy from solar radiation. The sugar molecules can then be chemically modified by these organisms through the metabolic addition of other elements to produce organic compounds such as cellulose, amino acids and proteins. Some of the organic matter that produced by plants is passed down to heterotrophic animals through consumption in ecosystems. The respiration process takes place in all organisms as a way to released carbon from ecosystems as carbon dioxide gas. Moreover, the microbes break down the organic carbon molecules into carbon dioxide gas and some other compound as by products.

Soil carbon sequestration or soil sink is a part of the carbon cycle that accumulates carbon for long periods of time. The organic matter in the soil contains two times the amount of carbon present in the atmosphere and close to three times the amount of carbon in living things on the Earth's surface (Bongen, 2009). In agricultural systems, some of the carbon remaining in the plant is then removed from the system when the plant is harvested. The organic matter in soil comes from agricultural residue, roots, and organisms that die in the soil and are partially decomposed into more stable carbon compounds. Some part is transformed into CO_2 again by microbes in the soil. This cycle is similar in all crop systems, but the quantities of carbon storage vary depending on climate, soil type, type of plant cover and management practices.

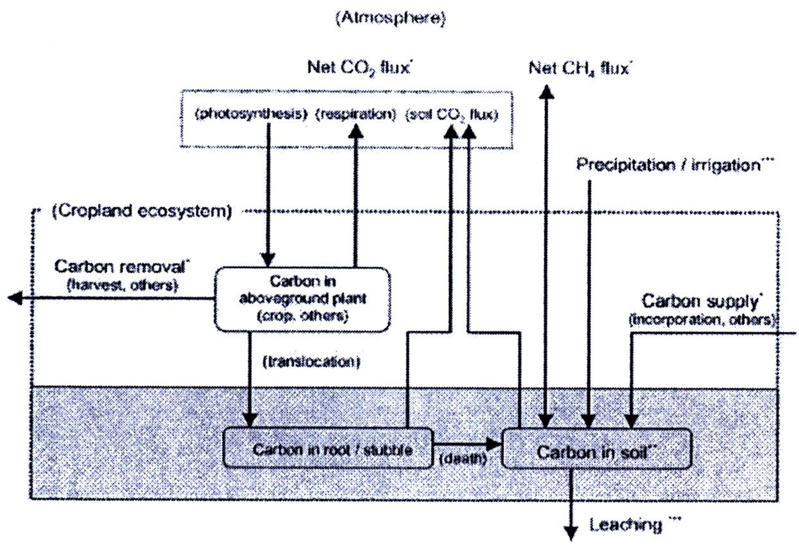


Figure 2.7 Schematic of carbon dynamics in cropland ecosystems (Nishimura et al. 2008).

Nishimura et al. (2008) studied the soil carbon budgets (SCB) of croplands. They found that the land use change from paddy rice cultivation to upland crop cultivation causes significant loss of carbon from cropland soil. The soil carbon budgets of the paddy plot were positive (79–137 $gC/m^2/y^1$), which indicates the accumulation of carbon in the soil. On the other hand, the upland rice and soybean-wheat plots were negative as -343 to-275 $gC/m^2/y^1$ and -361 to -256 $gC/m^2/y^1$, respectively. Moreover, they found the contribution of CH_4 emissions to SCB was small compared with that of CO_2 dynamics.

2.5 Rice straw management

Rice straw is the crop residues that are good sources of plant nutrients. About 40 percent of the nitrogen (N), 30 to 35 percent of the phosphorus (P), 80 to 85 percent of the potassium (K), and 40 to 50 percent of the sulfur (S) taken up by rice remains in vegetative plant parts at crop maturity (Dobermann and Fairhurst, 2002). Rice straws are retained in fields after rice harvest, making them valuable nutrient sources. The rice straw managements are different practice in rice-producing countries, for example, burned *in situ*, removed from the field, piled or spread in the field, incorporated in the soil, or used as mulch for the following crop. Open burning of straw is a common practice in India, Thailand and the Philippines, but removal of straw from the field is widespread in India, Bangladesh, and Nepal (Gadde et al., 2009). Straw can be used as fuel for cooking, ruminant fodder, and stable bedding or as a raw material in industrial processes. In the process, some or all of the nutrients contained in straw may be lost to the rice field, particularly where animal manure is used in other parts of the farming system where the response to straw application is greater than for rice.

Unlike removal or burning, incorporation of straw builds up soil organic matter, soil N, and increases the total and available P and K contents of the soil. Incorporation of the remaining stubble and straw into the soil returns most of the nutrients and helps to conserve soil nutrient reserves in the long-term (Singh et al., 2004). Short-term effects on grain yield are often small when compared with straw removal or burning, but long-term benefits are significant. Under optimum temperature and moisture conditions, N immobilization can last from four to six weeks. Adverse effects of wheat straw incorporation can be prevented by incorporating both green manure, having narrow C:N ratio, and cereal straw, having wide C:N ratio, into the soil before rice transplanting (Singh and Singh, 2001). Incorporation of large amounts of fresh straw into wet soil results in temporary immobilization of N and a significant increase in methane emission from rice paddy (Watanabe et al., 1993; Bossio et al., 1999; Fitzgerald, 1998).

2.6 The growth of rice plant

The growth of the rice plant is divided into three phases. These 3 growth phases consist of a series of 9 stages. This topic explains the specific physical changes in a growing rice plant (IRRI, 2002).

1. Vegetative phase (germination to panicle initiation);

Stage 0 - Germination to emergence : The period which is signified by the coming out of the radical or coleoptiles from the germinating embryo.

Stage 1 – Seedling : The period when a rice plant develops the first 5 leaves or so until tillers are developed.

Stage 2 – Tillering : The tillering refers to the production of tillers. A Tiller is a stem produced at the base of rice plants.

Stage 3 - Stem elongation : The increase in length of the 4th internodes of short-duration varieties below the point where the panicle primordial emerges.

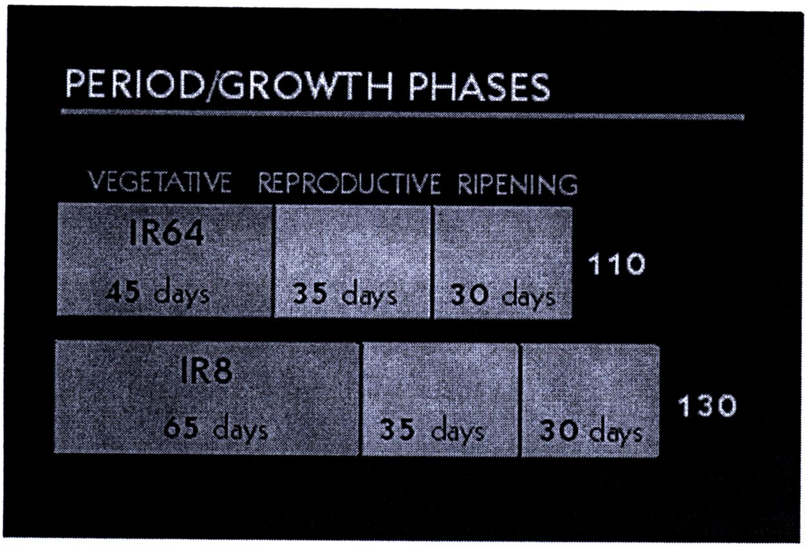


Figure 2.8 Growth stages of the rice plant (IRRI, 2002)

2. Reproductive phase (panicle initiation to flowering);

Stage 4 - Panicle initiation to booting : The bulging of the leaf sheath due to increase in size of the young panicle and its upward extension inside the upper leaf sheath.

Stage 5 – Heading : The emergence or coming out of the panicle from the flag leaf sheath.

Stage 6 – Flowering : The stage when the anthers of the terminal spikelet protrude and shed pollen.

3. Ripening phase (flowering to mature grain);

Stage 7 - Milk grain stage : The stage when the watery consistency of the caryopsis turns milky.

Stage 8 - Dough grain stage : The stage when the milky portion of the grain turns into a soft mass and later into a hard mass.

Stage 9 - Mature grain stage : The stage when the rice grains in the panicle are yellow, fully developed, and hard.