

CHAPTER 5
GREENHOUSE GASES EMISSIONS FROM INCORPORATED RICE FIELD
RESIDUE IN THE SOIL

5.1 Introduction

Incorporation is a way to manage rice residue that proposes to use instead of burning it [PCD, 2006]. Incorporation of rice residue into the soil is safe eco-friendly practice without any adverse effect on crop yield in the warmer regions, and it gradually improves soil organic carbon, phosphorus and potassium contents [Prasad, R. et al, 1999] but it leads to some problems as higher cost (compare to burning), increase weed carryover and increased GHG emissions due to flooding during rice cultivation [Summers, M.D.]. Rice straw is one of the organic materials which considered as a main factor influencing the source of CH₄ [Vibol, S., 2006]. Anaerobic decomposition of organic material in flooded rice fields produces methane (CH₄) [IPCC, 2006] so incorporated rice residue into the soil also affects to emission in rice cultivation. Comparison between no-straw and straw incorporated into the soil, straw incorporated increased CH₄ emission significantly about 3.9-10.5 times [Ma, J., et al, 2009] or 87% higher [Vibol, S., 2006].

The amount of CH₄ from rice cultivation is a function of the number and duration of crops grown, water regime before and during cultivation period, organic and inorganic soil amendments, soil type, and temperature [IPCC, 2006].

This part aims to estimate the emission from rice cultivation due to different amounts of rice residue incorporated into the soil.

5.2 Methodology

5.2.1 Estimation of CH₄ emissions from rice cultivation

This study estimates the emission from rice cultivation which has different amounts of rice residue incorporated into the soil. Based on 2006 IPCC Guideline, emission from rice cultivation is estimated based on Equations 5.1 to 5.3.

$$CH_4 = \sum_{i,j,k} (EF_{i,j,k} \times t_{i,j,k} \times A_{i,j,k} \times 10^{-6}) \quad \text{--- (Equation 5.1)}$$

Where:

CH₄ = annual methane emissions from rice cultivation, (Gg CH₄ yr⁻¹)

EF_{i,j,k} = a daily emission factor for i, j, and k conditions (kg CH₄ ha⁻¹day⁻¹)

$t_{i,j,k}$ = cultivation period of rice for i, j, and k conditions (day)

$A_{i,j,k}$ = annual cultivated area of rice for i, j, and k conditions (ha yr^{-1})

i, j, k = represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary

$$EF_i = EF_c \times SF_w \times SF_p \times SF_o \times SF_{s,r} \quad \text{--- (Equation 5.2)}$$

Where:

EF_i = adjusted daily emission factor for a particular harvested area

EF_c = baseline emission factor for continuously flooded fields without organic amendments

SF_w = scaling factor to account for the differences in water regime during cultivation period

SF_p = scaling factor to account for the differences in water regime in the pre-season before the cultivation period

SF_o = scaling factor should vary for both type and amount of organic amendment applied

$SF_{s,r}$ = scaling factor for soil type, rice cultivar, etc.

$$SF_o = \left(1 + \sum_i ROA_i \times CFOA_i \right)^{0.59} \quad \text{--- (Equation 5.3)}$$

Where:

SF_o = scaling factor for both type and amount of organic amendment applied

ROA_i = application rate of organic amendment i, in the dry weight for straw and fresh weight for other (tons ha^{-1})

$CFOA_i$ = conversion factor for organic amendment i

5.2.2 Parameters influencing CH_4 emissions

Based on Equations 5.1 to 5.3, main factors related to estimate emissions from rice cultivation included daily emission factor, cultivation period, and average cultivated area.

The information of each factor is shown in the following:

(1) Daily emission factor (EF_i)

The emission factor of rice cultivation depends on conditions of rice cultivation as rice ecosystem type, flooding pattern before and during cultivation period, and type and amount of organic amendments. Based on Equation 5.2, factors used to adjust the value of

base line emission factor (EF_c) are scaling factor for differences in water regime during cultivation period (SF_w), pre-season before the cultivation period (SF_p), scaling factor for type and amount of organic amendment (SF_o), and scaling factor for soil type and rice cultivar ($SF_{s,r}$).

Base line emission factor (EF_c)

A baseline emission factor for no flooded fields for less than 180 days prior to rice cultivation and continuously flooded during the rice cultivation period without organic amendments (EF_c) is used as a starting point. This study uses default value proposed by 2006 IPCC guidelines is about $1.30 \text{ kg CH}_4 \text{ ha}^{-1} \text{ day}^{-1}$.

Scaling factor for differences in water regime during cultivation period (SF_w)

SF_w is a factor used to adjust the base line emission factor due to the differences in water regime during cultivation period. Water regime during cultivation period considers the ecosystem type (irrigated/rain fed/deep water) and flooding pattern (continuous flood and intermittently/ regular rain fed/ drought prone/ deep water) during rice cultivation. The default value of SF_w for each case of water regime and flooding pattern during rice cultivation period is shown in Table 5.1.

Table 5.1 Default value of SF_w for different water regimes and flooding patterns during rice cultivation period

Water regime		Aggregated case		Disaggregated case	
		Scaling factor (SF_w)	Error range	Scaling factor (SF_w)	Error range
Upland		0	-	0	-
Irrigated	Continuously	0.78	0.62-0.98	1	0.79-1.26
	Intermittently flooded-single aeration			0.60	0.46-0.80
	Intermittently flooded-multiple aeration			0.52	0.41-0.66
Rain fed and deep water	Regular rain fed	0.27	0.21-0.34	0.28	0.21-0.37
	Drought prone			0.25	0.18-0.36
	Deep water			0.31	-

Source: IPCC, 2006

This study classified the water regime into 2 types: irrigated and rain fed. The scaling factor used in this study is 0.78 for irrigated area and 0.27 for rain fed area [IPCC, 2006].

Scaling factor to account for differences in water regime in the pre-season before the cultivation period (SF_p)

SF_p is a factor used to adjust the base line emission factor due to the differences in water regime in the pre-season before the cultivation period. Water regime in the pre-season considers on the duration of non-flooding before cultivation. In case of flooding before cultivation, only long flooding period (more than 30 days) is considered. The default value of scaling factor for each case of water regime before cultivation period is summarized as shown in Table 5.2.

Table 5.2 Default value of SF_p for difference in water regime before cultivation period

Water regime before rice cultivation period	Aggregated case		Disaggregated case	
	Scaling factor (SF_p)	Error range	Scaling factor (SF_p)	Error range
Non flooded pre-season < 180 d	1.22	1.07-1.40	1	0.88-1.14
Non flooded pre-season > 180 d			0.68	0.58-0.80
Flooded pre-season > 30 d			1.90	1.65-2.18

Source: IPCC, 2006

This study used aggregated default value proposed in 2006 IPCC guidelines which is 1.22 for all cases due to this study not focusing on the pattern of rice cultivation.

Scaling factor for type and amount of organic amendment applied (SF_o)

SF_p is a factor used to adjust the base line emission factor due to incorporated organic material into the soil. The value of SF_p depends on amount and type of organic material as straw, compost, manure, and so on. In case of straw, the duration of incorporation of straw into the soil also affects to the amount of CH_4 during rice cultivation. The default value of conversion factor for each type of organic amendment (CFOA) is shown in Table 5.3.

Table 5.3 Default value of conversion factor for each type of organic amendment

Organic amendment	Conversion factor (CFOA)	Error range
Straw incorporated shortly (< 30 days) before cultivation	1	0.97-1.04
Straw incorporated long (> 30 days) before cultivation	0.29	0.20-0.40
Compost	0.05	0.01-0.08
Farm yard manure	0.14	0.07-0.20
Green manure	0.50	0.30-0.60

Source: IPCC, 2006

Rice cultivation in Thailand mainly uses chemical fertilizer especially in the irrigation area. Based on questionnaire survey found rate of chemical fertilization is about 150-313 kg/ha for major rice and 231-369 kg/ha for minor rice. In case of compost or manure, it is used only in the rain fed area at rate 3.125 tons/ha [Rice Thailand, 2010]. The share of the area that uses compost or manure is about 14%, 0.6%, 7.75% and 1.93% for northern, north-eastern, central, and southern respectively [Office of Natural Resources and Environmental Policy and Planning, 2010]. From this information, this study assumes:

- Irrigation area, rice cultivation uses only rice residue as an organic amendment with a different rate.
- Rain fed area, 14% of the northern field, 0.6% of the north-eastern field, 7.75% of the central field, and 1.93% of the southern use 3.125 tons/ha of compost and different rate of rice residue. For the left area, there use only different rate of rice residue.

This study classifies the using of organic amendment for rice cultivation into 3 cases:

Case 1: Incorporated rice residue after burning

Farmer always burns rice residue in the field for clearing area and make it easier for tillage. The incorporation of rice residue after burned into the soil is the base case of application of organic amendment. The amount of residue that left after burning is shown in Table 5.4. In this case the incorporated residue is residue after burning. However, the amount of residue left after burning is closely to the general amount of unused stubble that incorporated into soil. So, the residue left after burning is not considered as the applied of organic carbon. The scaling factor for organic amendment applied considers only on compost. Based on Equation 5.3, the scaling factor for the field that uses compost (SF_o) is about 1.00 whereas without compost is about 1.09.

Table 5.4 Amount of incorporated residue (residue left after burning) and value of SF_o by region

Region	Amount of residue left after burning (tons/ha)		SF _o			
			W/O compost		W compost	
	Major	Minor	Major	Minor	Major	Minor
Eastern	2.40	6.28	1.09	1.09	1.00	1.00
Central	2.40	6.28	1.09	1.09	1.00	1.00
Western	2.40	6.28	1.09	1.09	1.00	1.00
Lower Northern	1.08	4.37	1.09	1.09	1.00	1.00
Upper Northern	1.08	4.37	1.09	1.09	1.00	1.00
Lower Northeastern	0.17	1.09	1.09	1.09	1.00	1.00
Upper Northeastern	0.17	1.09	1.09	1.09	1.00	1.00
Lower Southern	0.85	5.68	1.09	1.09	1.00	1.00
Upper Southern	0.85	5.68	1.09	1.09	1.00	1.00

Case 2: Incorporated unused stubble

Stopping open burning by incorporation affects to the amount of incorporated residue that leads to the emission from rice cultivation. The amount of unused stubble that incorporated into soil is shown in Table 5.5. The incorporated unused stubble into soil is not considered as the applied of organic carbon because the stubble is incorporated into soil in the pre-cultivation season is the common method which considered as a starting point of rice cultivation. In this case, there has no residue that incorporated into soil so the scaling factor for organic amendment applied consider only on compost. Based on Equation 5.3, the scaling factor for the field that uses compost (SF_o) is about 1.00 whereas without compost is about 1.09.

Table 5.5 Amount of incorporated residue (unused stubble) and value of SF_o by region

Region	Amount of unused stubble (tons/ha)		SF _o			
			W/O compost		W compost	
	Major	Minor	Major	Minor	Major	Minor
Eastern	2.91	8.54	1.09	1.09	1.00	1.00
Central	2.91	8.54	1.09	1.09	1.00	1.00
Western	2.91	8.54	1.09	1.09	1.00	1.00
Lower Northern	4.49	9.05	1.09	1.09	1.00	1.00
Upper Northern	4.49	9.05	1.09	1.09	1.00	1.00
Lower Northeastern	4.97	17.40	1.09	1.09	1.00	1.00
Upper Northeastern	4.97	17.40	1.09	1.09	1.00	1.00
Lower Southern	6.61	9.86	1.09	1.09	1.00	1.00
Upper Southern	6.61	9.86	1.09	1.09	1.00	1.00

Case 3: Incorporated unused residue (stubble and straw)

In this case the incorporated residue is the unused residue which the different rate as shown in Table 5.6. The scaling factor for organic amendment applied considers on compost and unused stubble and unused straw. Based on Equation 5.3, the rate of compost and the rate of unused stubble and unused straw under condition long incorporated before cultivation ($CFOA = 0.29$), the scaling factor for the field that uses compost (SF_o) and without compost is summarized as shown in Table 5.6.

Table 5.6 Amount of incorporated residue (unused stubble and unused straw) and value of SF_o by region

Region	Amount of unused stubble and straw (tons/ha)		SF_o			
			W/O compost		W compost	
	Major	Minor	Major	Minor	Major	Minor
Eastern	5.46	14.27	1.75	5.00	1.81	5.03
Central	5.46	14.27	1.75	5.00	1.81	5.03
Western	5.46	14.27	1.75	5.00	1.81	5.03
Lower Northern	4.16	13.67	1.60	4.88	1.66	4.91
Upper Northern	4.16	13.67	1.60	4.88	1.66	4.91
Lower Northeastern	2.39	5.21	1.36	2.94	1.44	2.98
Upper Northeastern	2.39	5.21	1.36	2.94	1.44	2.98
Lower Southern	2.43	12.90	1.37	4.73	1.44	4.76
Upper Southern	2.43	12.90	1.37	4.73	1.44	4.76

Scaling factor for soil type, and rice cultivar ($SF_{s,r}$)

SF_p is a factor used to adjust the base line emission factor due to the different types of soil and rice. This study does not focus on the scaling factor of soil type and rice cultivar because of lack of information.

The value of EF_i is estimated based on the value of EF_c , SF_w , SF_p , SF_o , and $SF_{s,r}$. The value of EF_i for each ecosystem of rice cultivation is shown in Table 5.7. Due to the pattern of organic amendment applied into soil in cases 1 and 2 is similar so these 2 cases have the same value of EF_i (as seen in Table 5.7).

Table 5.7 Summary of EF_i for each case

Water management	Water regime	OM	Region	EF_i (kg ha ⁻¹ day ⁻¹)	
				Case 1 and Case 2	Case 3
Major-Irrigated	Intermittently flooded	Straw	E, C, W	1.24	2.17
			L-N, U-N	1.24	1.97
			L-NE,U-NE	1.24	1.69
			L-S, U-S	1.24	1.69
		Straw and manure	E, C, W	1.35	2.24
			L-N, U-N	1.35	2.06
			L-NE,U-NE	1.35	1.78
			L-S, U-S	1.35	1.78
Major-Rain fed	Flood prone	Straw	E, C, W	0.43	0.75
			L-N, U-N	0.43	0.68
			L-NE,U-NE	0.43	0.58
			L-S, U-S	0.43	0.59
		Straw and manure	E, C, W	0.47	0.78
			L-N, U-N	0.47	0.71
			L-NE,U-NE	0.47	0.62
			L-S, U-S	0.47	0.62
Minor-Irrigated	Intermittently flooded	Straw	E, C, W	0.43	2.14
			L-N, U-N	0.43	2.09
			L-NE,U-NE	0.43	1.26
			L-S, U-S	0.43	2.02
		Straw and manure	E, C, W	0.47	2.15
			L-N, U-N	0.47	2.10
			L-NE,U-NE	0.47	1.28
			L-S, U-S	0.47	2.04
Minor-Rain fed	Flood prone	Straw	E, C, W	0.43	2.14
			L-N, U-N	0.43	2.09
			L-NE,U-NE	0.43	1.26
			L-S, U-S	0.43	2.02
		Straw and manure	E, C, W	0.47	2.15
			L-N, U-N	0.47	2.10
			L-NE,U-NE	0.47	1.28
			L-S, U-S	0.47	2.04

(2) Cultivation period

The period of cultivation depends on type of rice seed that used in each area. This data obtained from questionnaire survey. The period of cultivation of each area is between 92 and 120 days for major rice and between 115 and 140 days for minor rice.

(3) Average cultivated area

In this stage the cultivated area is the area that rice residue is incorporated into the soil. This study assumes the cultivated area is the paddy field area that opens burning. So, the cultivated area equals to the amount of burned area. The amount of cultivated area varies on region and type of rice. It varies on 0.02-0.62 Mha for major rice and 0.006-0.46 Mha for minor rice. The amount of cultivated area classified by region and type of rice obtained from questionnaire survey is shown in Table 5.8.

Table 5.8 The amount of cultivated area by region and type of rice

Region	Cultivated area/(SE) (Mha)		
	Major rice	Minor rice	Total
Eastern	0.238 (0.017)	0.075 (0.007)	0.31
Central	0.337 (0.045)	0.458 (0.017)	0.80
Western	0.198 (0.016)	0.316 (0.014)	0.51
Lower-Northern	0.620 (0.083)	0.354 (0.020)	0.97
Upper-Northern	0.285 (0.025)	0.061 (0.003)	0.35
Lower-Northeastern	0.447 (0.058)	0.013 (0.001)	0.46
Upper-Northeastern	0.398 (0.035)	0.035 (0.003)	0.43
Lower-Southern	0.042 (0.004)	0.011 (0.002)	0.05
Upper-Southern	0.024 (0.004)	0.006 (0.001)	0.03
Total	2.590	1.331	3.92

5.3 Results and Discussion

The information of emissions from rice cultivation in each pattern classified by region is reported in Table 5.9. The estimation found the total GHG from rice cultivation in the burned area (Case 1) is about 0.50 Mt of CH₄ which equals to the rice cultivation when incorporated unused stubble (Case 2) due to the same amount of organic applied. The regional of GHG emissions from rice cultivation is in the range of 2,602 to 72,379 t of CH₄. The highest of GHG (72,379 t CH₄) is emitted in the central region due to this region has the largest of the burned area. The lowest of GHG (2,602 t CH₄) is emitted in the upper southern region due to this region has the smallest of the burned area.

The total GHG from rice cultivation after incorporation 2.39-14.27 t/ha of unused residue into the soil (Case 3) is about 0.72 Mt of CH₄. The regional of GHG emissions from rice cultivation after incorporation of unused straw is in the range of 4,693 to 194,277 t of CH₄. The highest of GHG (194,277 t CH₄) is emitted in the central region. The lowest of GHG (4,693 t CH₄) is emitted in the upper southern region due to this region has the minimum of the burned area and low amount of unused rice residue.

Table 5.9 The amount of CH₄ from rice cultivation by region and case study

Region	Emission CH ₄ (tons CH ₄)	
	Case 1 and Case 2	Case 3
Eastern	33,776	71,494
Central	67,977	194,277
Western	42,554	126,377
Lower-Northern	72,379	175,731
Upper-Northern	27,624	54,352
Lower-Northeastern	25,960	36,479
Upper-Northeastern	30,301	44,152
Lower-Southern	4,615	8,270
Upper-Southern	2,602	4,693
Total	307,789	715,826
Total (tons CO_{2eq})	6,463,571	15,032,339
Ave. Flux emission (tons CO_{2eq}/ha)	1.65	3.83
SD (tons CO_{2eq}/ha)	0.101	0.110

Take into account of flux of emission found the amount of CH₄ in unit area is about 1.65-3.83 tCO_{2eq}/ha. In the literature review, the flux emission from rice cultivation in Thailand is in the range of 1.57-9.25 t CO_{2eq}/ha [ONEP, 1990] under different pattern of rice cultivation. The lowest value (1.57 tCO_{2eq}/ha) is under condition drought prone in rain fed area, without organic amendment. The highest value (9.25 tCO_{2eq}/ha) is under condition continuously flooded in irrigated area, with organic amendment.

The study on the relationship between GHG emissions and amount of residue incorporated into the soil (as seen in Figure 5.1) found under condition 120 days of rice cultivation, 3.125 tons/ha of compost, when a ton of incorporation of residue increased, the GHG emissions in term of equivalent of CO₂ from rice cultivation will be increased 1.19 tCO_{2eq}/ha and 0.14 tCO_{2eq}/ha for irrigated area and rain fed area respectively. It demonstrates, GHG emission in irrigated area has been increased more than rain fed area because of the higher value of the scaling factor for water regime (SF_w) and the conversion factor for duration of straw incorporated before cultivation.

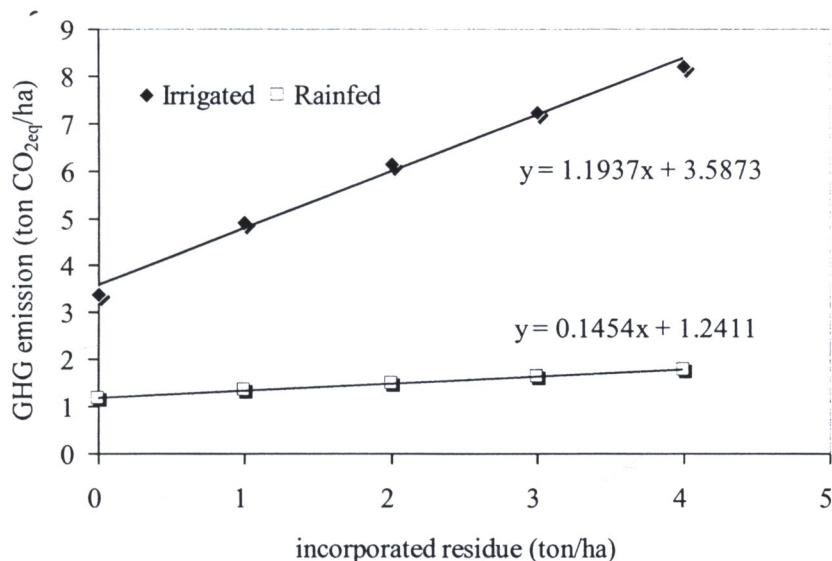


Figure 5.1 Relationship between incorporated residue and GHG emission

In case of none of the straw is incorporated into the soil, the emissions from rice cultivation is in the range of 1.24-3.59 t CO_{2eq}/ha (under condition: rice cultivation in the irrigated area or rain fed area, manure 3.125 t/ha, cultivation duration 120 days). This value equals to the value of emission factor of rice cultivation. According to the literature review on emissions from rice cultivation, the emission factor (EF) of rice cultivation in Thailand is about 1.785-10.29 tCO_{2eq}/ha [Jiaphasuanan, T. et al., 2006; San, V., 2005; Supparattanapan, S., 2009; Fusuwankaya, K., 2009]. Therefore, emission factor in this study is consistent to the result from previous study. The value of emission factor is quiet varies due to the varieties of rice cultivation pattern.

These results demonstrate the different amount of rice residue incorporated into the soil, the different emission is emitted from rice cultivation. Incorporating rice residue into the soil increased CH₄ about 29% of rice cultivation in burned field. This result agrees with the result of Ma J. et al. (2009) that reported CH₄ emission in rice cultivation increased significantly about 3.9-10.5 times when incorporating straw. This result accords to the study of M.D. Summers that reported incorporation of straw into the soil in winter flooding of the rice field has increased atmospheric emission of methane and nitrogenous. This result also accords to the study of San Vibol that studied on the effect of rice straw management and reported the CH₄ the seasonal emission of CH₄ during cropping season in

the rice straw incorporation was the highest comparing to stubble with and without fertilizer and straw burned in the paddy field with and without fertilizer.

5.4 Conclusions

This part studied the effects of emission from rice cultivation due to different amount of rice residue incorporated into the soil based on 2006 IPCC guideline. The amount of rice residue incorporated into the soil was classified into 3 cases: (1) incorporation after burning, (2) incorporation unused stubble and (3) incorporation unused stubble and unused straw.

Based on 2006 IPCC guideline found the rice residue was a kind of organic carbon that affect to the GHG emission from rice cultivation. The starting point of the emission factor (EF_c) was $1.30 \text{ kg CH}_4 \text{ ha}^{-1} \text{ day}^{-1}$ under pattern no flooded fields for less than 180 days prior to rice cultivation and continuously flooded during the rice cultivation period without organic amendments (included stubble). The difference amount of residue (only straw) affected to the scaling factor for amount of organic carbon applied (SF_o). Incorporation after burning and Incorporation only stubble were not considered in the adjustment of scaling factor for organic carbon applied because it is the common practice which considered in the starting point of emission factor. Under the assumption, the incorporation before rice cultivation more than 30 days and 3.125 t/ha of manure applied, the scaling factor for amount of organic carbon applied was

- In the case of incorporation after burning ($0.17\text{-}6.28 \text{ t/ha}$ of rice residue left after burning), unburned residue was not considered as organic applied, the SF_o was about 1.00 for with manure and 1.09 for without manure.
- In the case of incorporation unused stubble ($2.92\text{-}17.40 \text{ t/ha}$ of unused stubble), unused stubble was not considered as organic applied, the SF_o was about 1.00 for with manure and 1.09 for without manure.
- In the case of incorporation unused stubble and unused straw ($2.39\text{-}14.27 \text{ t/ha}$ of unused stubble and unused straw), the SF_o was about 1.36-5.00 for with manure and 1.44-5.03 for without manure.

The difference of SF_o involved the value of emission factor (EF). The value of EF varies on 0.43 to $2.15 \text{ kg ha}^{-1} \text{ day}^{-1}$. The lowest value ($0.43 \text{ kg ha}^{-1} \text{ day}^{-1}$) is used under the pattern of the major rice-rain fed-without manure in the central, the western, and the eastern. The highest value ($2.15 \text{ kg ha}^{-1} \text{ day}^{-1}$) is used under the pattern of minor rice-irrigated-with

manure in the central, the western, and the eastern regions. The value of emission factor is varies due to the varieties of rice cultivation pattern.

According to the current pattern of rice cultivation which incorporation after burning and incorporation stubble (Cases 1 and 2) found, the total GHG emission from rice is about 6.46 MtCO_{2eq} or about 1.65 tCO_{2eq}/ha. In case of unused stubble and unused straw incorporated into the soil, the emission from rice cultivation will be about 15.03 MtCO_{2eq} or about 3.83 tCO_{2eq}/ha.

In case of no straw is incorporated into the soil, the emission from rice cultivation is in the range of 1.24-3.59 t CO_{2eq}/ha (under condition: rice cultivation in the irrigated area or rain fed area, manure 3.125 t/ha, cultivation duration 120 days).

In case of straw incorporated into the soil, the emission from rice cultivation is increased, If increase a ton of residue incorporated into the soil, the emission from rice cultivation will increase between 0.14 and 1.19 t CO_{2eq} under condition 120 days of rice cultivation and 3.125 tons/ha of compose.

The proper management method is able to reduce CH₄ emission. One way is to reduce the effected of CH₄ emissions from rice cultivation is incorporation more than 30 days before plantation. This method is supported by the report of Dobermann, A. and Fairhurst, T.H. that proposed incorporation should be carried out 2-3 weeks after harvesting due to the smaller CH₄ emission compared with straw incorporated during land preparation season. Another way is mulching of straw in zero-tillage. This way also enhances CH₄ emissions but increased in the lower rate [Charoensilp, N. et al., 2000].

