CHAPTER 6
INVENTORY OF EMISSION LOAD FROM AGRICULTURAL OPEN BURNING IN THAILAND

Emission load from agricultural open burning in Thailand is obtained by results of the experiments in this study, including biomass load from field experiments, emission factor from field and chamber experiments, and burned area from statistical and remote sensing data, which these information is available in Chapter 3-5. Methodology of estimating emission load is explained as followings.

6.1 Emission Inventory of Agricultural Residues Open Burning Year 2007

The data for emission inventory assessment calculation is presented in Table 6.1.

Table 6.1 Data for emission load assessment

Biomass type	A (1,000 ha/y)	BL (g/m^2)	FB (%)	CE (%)	EF (g/kg)
Irrigated rice straw	1,207	507±305	100	100	BC 0.72 ±0.03 CO_2 1,378±157 CO 161±101 $PM_{2.5}$ 40.54 ±3.70
Rain-fed rice straw	3,901	421±236	100	100	BC 0.79 ±0.36 CO_2 1,030 ±241 CO 111.35 ±30.19 $PM_{2.5}$ 17.30 ±9.55
Total Rice straw	2,694	360±140	100	100	BC 0.77 ±0.31 CO_2 1,185±271 CO 133 ±75 $PM_{2.5}$ 28 ±14
Corn residues	139	610±153	100	67±18	BC 0.55±0.34 CO_2 1,186 ±594 CO 68.11±45.78 $PM_{2.5}$ 8.72±9.31
Sugarcane leaves	614	1,007±295	100	100	BC 0.71 CO_2 1,181±248 CO 123.76±45.40 $PM_{2.5}$ 20.31±15.02

Irrigated burned area of rice field in major rice is 1,601,550 ha and second rice is 1,092,390 ha, which most area is located in central region of Thailand. Rain-fed burned area of paddy field is 964,450 ha in major rice and 242,910 ha in second rice, which is mainly located in northern region of Thailand. Total burned area of rice field is 3,901,300 ha, which is 36.56% of total harvested area 10,669,000 ha (OAE, 2008). Burned area of corn field is 139,000 ha, which is 14.99% of total harvested area 928,000 ha (OAE, 2008). Burned area of sugarcane field is 614,000 ha, which is 54.65% of total cultivated area 1,093,924 ha or 55.81% of cultivated area for sugar factory 1,048,985 ha, not included for seeding (OCSB, 2008).

Fraction burn (FB) is accounted for in burned area of rice, corn, and sugarcane field so there is no utilization of residues in these areas, and total agricultural residues are burned (100%). Combustion efficiency (CE) of rice straw is considered in row of straw at the paddy field and in the chamber experiment, which total rice straw is burned. Corn residues' CE is 67%±18%, which stem usually remains after burning. From biomass load and burned area results, total amount of agricultural residues burning is presented in Table 6.2.

Table 6.2 Amount of agricultural residues burning in Thailand

Biomass type	Amount of biomass burned (ton/y)
Irrigated rice straw	9,698,400
Rain-fed rice straw	6,119,490
Total rice straw	16,423,210
Corn residues	847,900
Sugarcane leaves	6,182,980
Total amount	22,049,730

Total amount of rice, corn, and sugarcane burned is 22 Tg annually. These crop types are major agricultural burned residues in Thailand. Crop residue burned in this study is larger than estimated by Streets et al. (2003), 7.7 Tg annually because of roughly estimate from RPR, dry matter fraction (Koopmans and Koppejan, 1997), dry matter burn in the field (Hao and

Liu, 1994) and burn efficiency (Turn et al., 1997). Detail of difference between this study and Streets et al. (2003) is presented in Table 6.3.

Table 6.3 Detail of Amount of biomass burned difference between this study and Streets et al. (2003)

Crop type	Streets et al., 2003 RPR[a]	this study RPR	Streets et al., 2003 CE[b]	this study CE	Streets et al., 2003 %burn in field[c]	This study %burn in field
Corn	0.50	0.97	0.92	0.67	17	14.99
rice	0.57	0.72	0.89	1	17	36.56
sugarcane	3.33	0.28	0.68	1	17	55.81

Note: [a]Koopmans and Koppejan, 1997; [b]Turn et al., 1997; [c]Hao and Liu, 1994

Amount of crop burned estimated by foreign data, not specific to Thailand, so the amount is lower than this study. From information in Table 6.1, emission load of agricultural residues open burning in Thailand is estimated. Results of emissions load from agricultural open burning are presented in Table 6.4.

Table 6.4 Emission load from agricultural open burning in Thailand

Biomass type	Emission load (ton/y)			
	BC	CO_2	CO	$PM_{2.5}$
Irrigated rice	6,983	10,208,913	1,192,769	300,044
Rain-fed rice	4,834	6,303,075	679,263	105,867
Total Rice[a]	12,646	19,461,504	2,184,287	459,850
Corn residues	434	935,217	53,708	6,876
Sugarcane leaves	4,276	7,111,817	745,265	122,304

Note: [a]Emission laod of total rice derived from average BL and EF of irrigated and rain-fed rice.

6.2 Share of Emission Load in Each Crop Type

Major crop types that agricultural residues are usually burned in the field are rice, corn, and sugarcane, which are important economic crops in Thailand. In order to consider share of emission load in each crop type, percentage of emission load is presented in Figure 6.1-6.4.

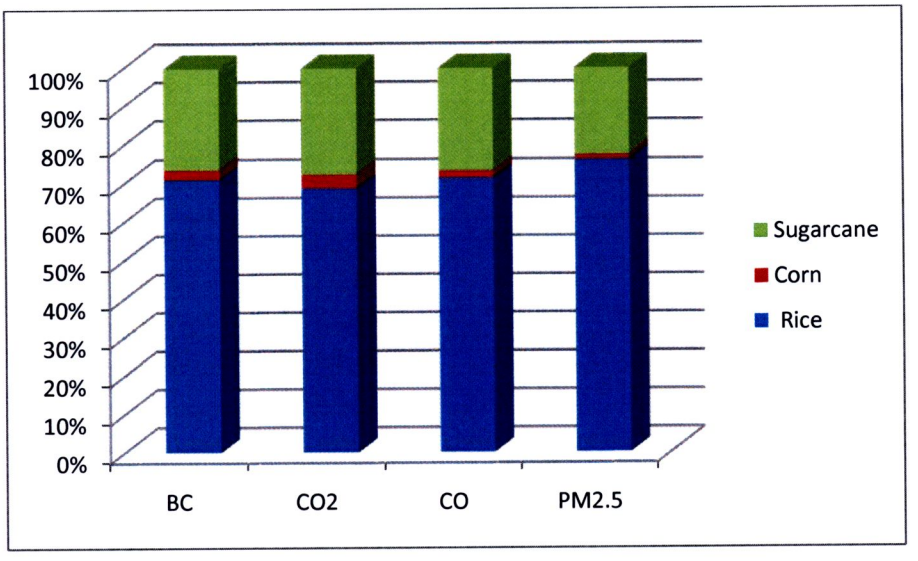

Figure 6.1 Share of BC, CO_2, CO, and $PM_{2.5}$ emission load in rice, corn, and sugarcane field.

From Figure 6.1, major share of BC, CO_2, CO, and $PM_{2.5}$ emission load is from rice field open burning for 71%, 69%, 71%, and 76%, respectively. The second share of emission load is from sugarcane field for 25% BC, 27% CO_2, 27% CO, and 23% $PM_{2.5}$, respectively. Emission load from corn field is so small 3% BC, 4% CO_2, 2% CO, and 1% $PM_{2.5}$, which are less than 5% and negligible. Therefore, major crop that residues are burned and release emissions into the air is rice for 72%±3%, and the second is sugarcane for 26%±2%.

6.3 Emission Load from Agricultural Open Burning in Each Region of Thailand

Estimation of emission load from rice, corn, and sugarcane residues in each region of Thailand is classified by harvested area in each region report by agricultural statistic data (OAE, 2008) and sugarcane factory (OCSB, 2008). Based year of emission load consideration is 2007 because of available harvested area data. Detail of results classified by crop type in each region is presented in Table 6.5.

Table 6.5 Emission load of BC, CO_2, CO, and $PM_{2.5}$ from paddy field in each region of Thailand

	BC (ton/y)	CO2 (ton/y)	CO (ton/y)	$PM_{2.5}$ (ton/y)
Irrigated major rice				
Thailand	**4,440**	**6,832,196**	**766,820**	**161,436**
North	1,452	2,234,546	250,797	52,799
Northeast	1,372	2,112,192	237,065	49,908
Central	1,503	2,313,625	259,673	54,668
South	112	171,833	19,286	4,060
Irrigated second rice				
Thailand	**3,028**	**4,660,118**	**523,034**	**110,112**
North	580	893,206	100,250	21,105
Northeast	88	136,147	15,281	3,217
Central	2,325	3,578,563	401,645	84,557
South	34	52,201	5,859	1,233
Rainfed major rice				
Thailand	**3,521**	**6,738,123**	**787,255**	**200,481**
North	1,382	2,645,048	309,037	78,699
Northeast	1,240	2,372,445	277,187	70,588
Central	794	1,519,976	177,588	45,224
South	105	200,654	23,444	5,970
Rainfed second rice				
Thailand	**736**	**1,409,238**	**164,650**	**41,929**
North	631	1,207,975	141,135	35,941
Northeast	49	93,318	10,903	2,777
Central	43	83,211	9,722	2,476
South	13	24,734	2,890	736
Rice (Total)				
Thailand	**11,725**	**19,639,675**	**2,241,760**	**513,959**
North	4,046	6,980,776	801,219	188,545
Central	4,666	7,495,374	848,627	186,925
Northeast	2,749	4,714,103	540,435	126,490
South	263	449,422	51,478	12,000

Irrigation is provided in every region of Thailand and mainly available in central region. In central region, irrigated paddy can be cultivated for 2-3 cycles in a year. While other regions can cultivate once a year so emission load is less in second rice at northern, northeastern and southern region. Major source of emission load from open burning of rice

residues in irrigated area is central region of Thailand. In the area that cannot access irrigation, rain is a water resource. Rainfed paddy field is distributed in many parts of Thailand, especially in north and northeast. Major rice is usually cultivated in rain-fed area in rainy season, but out of rainy season only few areas can be cultivated because of not sufficient water resource. Therefore, second rice is less in rain-fed area and consequently less emission load is found in rainfed second rice. Results of emission load estimation in corn field open burning are presented in Table 6.6.

Table 6.6 Emission load of BC, CO_2, CO, and $PM_{2.5}$ from corn field in each region of Thailand

Corn	BC (ton/y)	CO_2 (ton/y)	CO (ton/y)	$PM_{2.5}$ (ton/y)
Thailand	**313**	**674,366**	**38,728**	**4,958**
North	189	406,543	23,347	2,989
Northeast	65	140,973	8,096	1,036
Central	59	126,850	7,285	933

Major emission source of corn residues open burning in the field is northern region of Thailand. Northeast and central regions are the second source of emission load from corn residues open burning. There is no cultivation of corn in southern region so no emission load of corn residues open burning is found in south. However, corn residues emission load is so small when compare with emission load from open burning in the rice field. It is consistent with the field survey that many corn residues are ploughed back into the soil to prepare land for a rotation crop i.e. sunflower in Nakhonsawan. Results of emission load from sugarcane field open burning are presented in Table 6.7.

Table 6.7 Emission load of BC, CO_2, CO, and $PM_{2.5}$ from sugarcane field in each region of Thailand

Sugarcane	BC (ton/y)	CO_2 (ton/y)	CO (ton/y)	$PM_{2.5}$ (ton/y)
Thailand	**4,389**	**7,300,783**	**765,068**	**125,554**
North	1,056	1,756,778	184,097	30,212
Northeast	1,612	2,682,017	281,055	46,123
Central	1,285	2,136,934	223,935	36,749
East	328	545,227	57,136	9,376

Region of sugarcane residues open burning is classified into north, northeast, central, and also classified eastern region because the east is also an important sugarcane cultivated area in Thailand. Information of burned area of sugarcane is available in each by information of burned product from the sugar factory. The region that fraction of burned product maximum is north for 74%, east 65%, northeast 53% and center 51% in agricultural year 2006/2007. Trend of burned product is increased from 2006 to 2009 because harvested labor is scarce in Thailand. The farmers in the east and central regions have to make contract with the labor from northeastern region to harvest in their farms. Burning of sugarcane is decided by the labor because sugarcane leaves is sharp and harmful to the labor, but the farmers not satisfied with burning before harvesting because the production price is decreased for burned production. Emission load from agricultural open burning in each region is presented as the following: Results of emission load from open burning of rice, corn, and sugarcane field in each region of Thailand are presented in Figure 6.2-6.5 and Table 6.8-6.11.

a) Northern Region

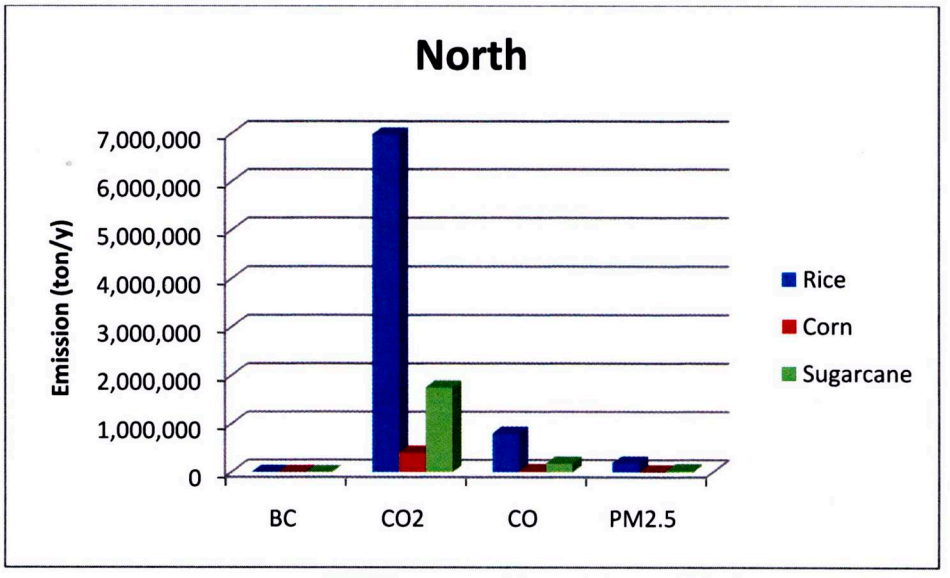

Figure 6.2 Graph of Emission load from agricultural open burning in northern region of Thailand, 2007.

Table 6.8 Emission load of BC, CO_2, CO, and $PM_{2.5}$ from agricultural open burning in north, 2007

North	BC (ton/y)	CO_2 (ton/y)	CO (ton/y)	$PM_{2.5}$ (ton/y)
Rice	4,046	6,980,776	801,219	188,545
Corn	189	406,543	23,347	2,989
Sugarcane	1,056	1,756,778	184,097	30,212

Emission load from agricultural open burning in the northern region is mainly from the paddy field, the second is from sugarcane field, and minor is from corn field. Agricultural residues open burning is one source of smoke problem in the north that usually occurs in dry season during February to April that smoke is generated from various sources of open burning, especially forest fire. Therefore, open burning in the agricultural field should be restricted during dry season to reduce aerosol problem that is harmful to human health and environment.

b) Central Region

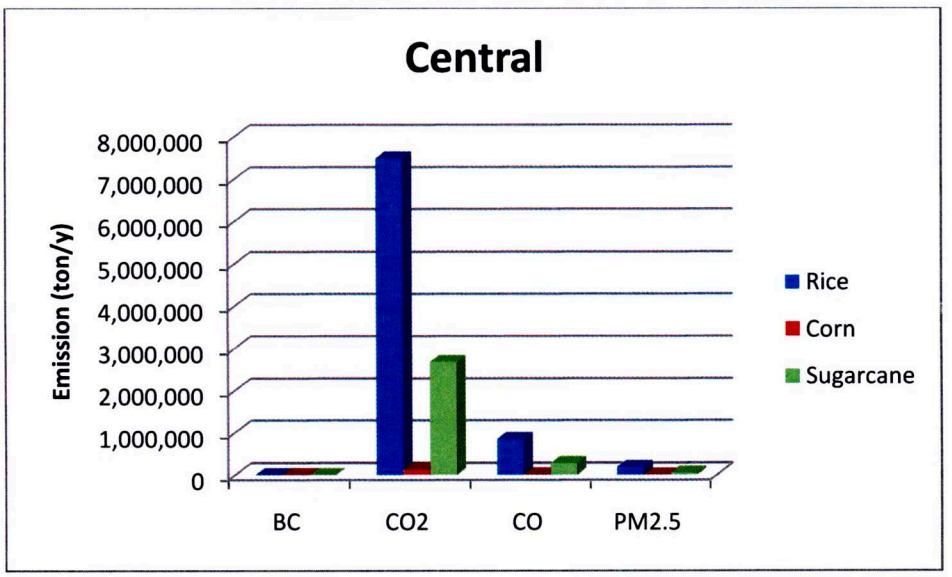

Figure 6.3 Graph of Emission loads from agricultural open burning in central region of Thailand, 2007.

Table 6.9 Emission load of BC, CO_2, CO, and $PM_{2.5}$ from agricultural open burning in central, 2007

Central	BC (ton/y)	CO_2 (ton/y)	CO (ton/y)	$PM_{2.5}$ (ton/y)
Rice	4,666	7,495,374	848,627	186,925
Corn	59	126,850	7,285	933
Sugarcane	1,612	2,682,160	281,070	46,126

In central region, agricultural residues open burning is a serious problem, especially in the paddy field that releases high amount of aerosols and gases. Paddy field in irrigated area can be cultivated for 2-3 times per year so burning is usually done to clear and prepare the land for the next cultivation. The problem is also found in rain-fed area because the rice residues are cleared by burning to catch the mice. Few amount of straw is utilized for animal feeding, mulching, and mushroom medium because of characteristic of straw that is high volume and difficult to collect and transport. Although, price of rice straw is quite high but collection and transportation technology is limited so rice straw is burned without any emission load control in the field. Sugarcane leaves open burning before harvesting in central region including Kanchanaburi, where is an important cultivation of Thailand so the emission load is high. In sugarcane field, burning is done before harvesting to remove leaves that are difficulty in harvesting by labor.

c) Northeastern Region

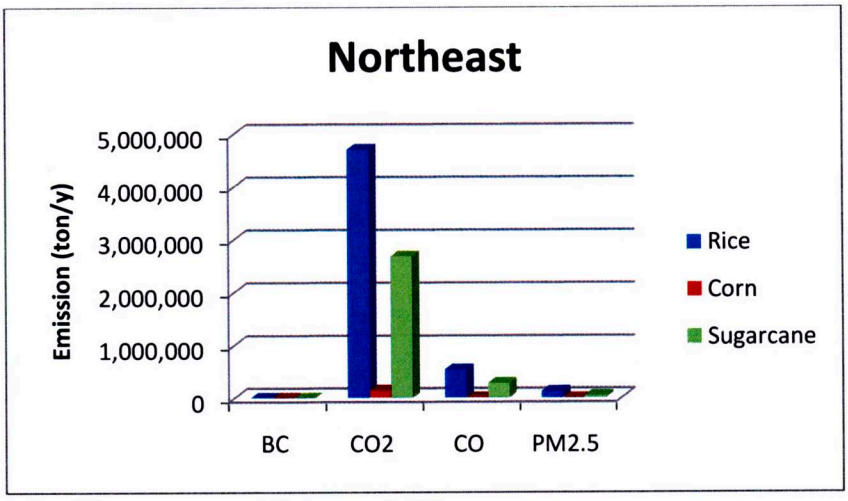

Figure 6.4 Graph of Emission loads from agricultural open burning in northeastern region of Thailand, 2007.

Table 6.10 Emission load of BC, CO_2, CO, and $PM_{2.5}$ from agricultural open burning in northeast

Northeast	BC (ton/y)	CO_2 (ton/y)	CO (ton/y)	$PM_{2.5}$ (ton/y)
Rice	2,749	4,714,103	540,435	126,490
Corn	65	140,973	8,096	1,036
Sugarcane	1,612	2,682,017	281,055	46,123

Major emission load from agricultural open burning in northeastern region (NE) of Thailand is from rice and the second is from sugarcane. Main water resource of rice in NE is rain so season of major rain-fed rice harvesting is main period of emission load released from agricultural open burning in NE, which is August to April during dry season. Little burning is found in second rain-fed rice, which is negligible. Emission load from corn residues open burning is also negligible because of low quantity when compared with rice and sugarcane. Open burning in sugarcane field is significant in NE because trend of cultivation is increased annually due to renewable energy policy of the country.

d) Southern Region

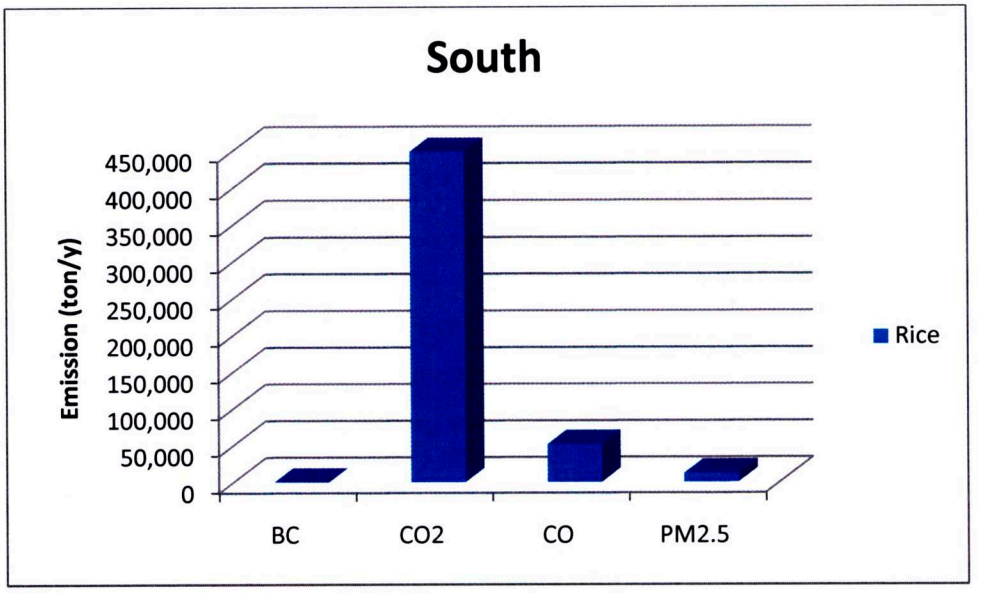

Figure 6.5 Graph of Emission loads from agricultural open burning in southern region of Thailand, 2007.

Table 6.11 Emission load of BC, CO_2, CO, and $PM_{2.5}$ from agricultural open burning in south

South	BC (ton/y)	CO_2 (ton/y)	CO (ton/y)	$PM_{2.5}$ (ton/y)
Rice	263	449,422	51,478	12,000

Only open burning of rice residues is found in the southern region, which is very small when compare with other regions because cultivated area in the south is limited by topography that surrounded by the sea and soil conditions are not suitable for cultivation. Therefore, open burning of agricultural residues is not a problem in this region. However, southern region of Thailand suffers from transboundary haze from forest fire in Indonesia from July to September because of south-west wind direction in rainy season of Thailand. Thus, agricultural open burning should be limited during this season.

6.4 Conclusions

1) Emission load inventory of agricultural open burning in Thailand 2007 has been estimated by using biomass load, emission factor, combustion efficiency, and fraction burn data from experiments; and burned area from literature review

2) Trend of rice and sugarcane open burning in the field is increasing, while corn open burning in the field is decreasing

3) Major share of BC, CO_2, CO, and $PM_{2.5}$ emission load is from rice field open burning for 72%±3%. The second share of emission loads is from sugarcane field for 26%±2%. Emission load from corn field burning is so small, which are less than 5% and negligible.

4) Paddy field open burning was found in every region of Thailand, especially central region. Corn field open burning was mainly in northern region of Thailand. Sugarcane field open burning was mainly in northeastern region of Thailand. Agricultural open burning in southern region was not significant, burning of corn and sugarcane could not be found in southern region.