CHAPTER 5
ASSESSMENT OF BURNED AREA

Agricultural burned area of rice, corn, and sugarcane field in Thailand was estimated by two approaches consisting of remote sensing based and ground based data.

5.1 Remote Sensing Data

Remote sensing data can overcome difficulties in measurement of large areas. Remote sensing data were used to quantify emission load from agricultural residues open burning in various area of the Earth that found several biomass burning (McCarty, 2006; and Bucini, and Lambin, 2001). However, most results were underestimating burned area (Chuvieco et al., 2007; Conard et al., 2002; Eva and Eric, 1998; Giglio et al., 2009). Therefore, ground base observation and statistical data are useful to improve the burned area estimation. In order to select satellite data to estimate biomass load, basic criteria of considerations are as follows:

1) Spatial resolution: Spatial resolution is considered by size of scope area. For national/province level, TERRA/AQUA-MODIS, NOAA, LANDSAT, IRS, RADARSAT can be applied. At the higher resolution scale SPOT-5, MODIS 250 m resolution, and THEOS can be applied.

2) Spectral resolution: Band ranges of remote sensing data that can identify agricultural residues open burning.

3) Temporal resolution: Time scale of data analysis is monthly data in based year 2008.

4) Timelines: Duration of interested agricultural practice is burning period of rice, corn, and sugarcane. For these reasons, active fire information from MODIS is selected to analyze for agricultural burned area, which detail of MODIS is explained as follows.

5.1.1 Description of MODIS

a) Characteristics of MODIS

MODIS (Moderate-resolution Imaging Spectroradiometer) is a scientific instrument launched into Earth orbit 705 km above the Earth by NASA in 1999 on board the Terra (EOS AM) Satellite, and in 2002 on board the Aqua (EOS PM) satellite. Characteristics of MODIS

are presented in Appendix D. The resolution that applied in this study is 1,000 m because we consider the whole country in national level.

b) Orbit of MODIS Terra and Aqua

Terra and Aqua orbit is moving around the Earth in north-south direction by Terra's orbit, passes from north to south across the equator in the morning, while Aqua's orbit passes south to north over the equator in the afternoon.

Examples of Terra's orbit on December 29, 2009 are presented in Appendix D. The map has a series of white lines with tick marks on them that show time (Coordinated Universal Time, or UTC) of Terra satellite passing over a particular location on Earth. The white lines are the center of the swath. The time presents start time of the northern (Terra) (southern for Aqua) edge of each 5-minute data collection period. An image of MODIS will span roughly 1,150 kilometers on either side of the tick mark. At 3:55 GMT (10:55 local time) on December 29, 2009, Terra passed over Thailand; but during the same period at 3:00 (10:00 local time) on the next day Terra shifted to pass over Gulf of Thailand and passed over Thailand at 15:30 (22:30 local time). Therefore, Terra's orbit to pass over Thailand takes around 12 hr at 10 AM and 10 PM (local time) but Terra's orbit does not pass over exactly the same place in order to cover the Earth area. Consider from orbit images, Terra will pass over center of Thailand every 7-9 days.

Aqua satellite's orbit is similar to orbit of Terra but different time. Examples of Aqua's orbit are presented in Appendix D. Aqua satellite passes over Thailand at around 7:00 am and 7:00 pm GMT (14:00 and 2:00 local time). Considering orbit images of Aqua, the satellite will pass over center of Thailand every 7-9 days. However, Aqua and Terra orbits switch to pass at least one time exactly over Thailand on each day i.e. Terra passed over Thailand on December 30, while Aqua passed over the ocean.

5.1.2 MODIS Fire Product

a) Description of MODIS fire product

Fire hot spot data provides information of location and time of fires burning. Fire hot spot is detected by 4 μm channel 21 and 22 saturates at nearly 500 and 331 K, respectively. Channel 22 with low-saturation is less noisy and has a small quantization error so the fire is

derived from this channel whenever possible. When missing data of these 21 and 22 channels occur, it is computed from 11 μm channel 31 that saturates at 400 K. The 12 μm channel 32 is used for cloud masking.

b) Fire detection by MODIS

MODIS can detect both flaming and smoldering fire in resolution 1,000 m^2 area size under very good observing condition.The smallest fire size that MODIS can detect is 50 m^2 (MODIS Fire Users Guide 2.4). Therefore, burning in agricultural field can be detected by MODIS.

c) Detection confidence of MODIS data

Fire detection is based on absolute detection of a fire or fire strength is sufficient to be detected, and on detection relative to its background of the surface temperature and reflection by sunlight. A detection confidence is a classified range in three fire classes: low-confidence fire, nominal-confidence fire, and high-confidence fire. Classification of these three levels depends on false alarm rate. The range of high confidence level is 71-100%, nominal (moderate) confidence level is 31-70%, and low confidence level is 0-30%. Higher confidence level presents lower number of fire hotspot on agricultural area. At 100% confidence seems to present too low quantity number of fire hotspot, which does not represent real condition in Thailand. Underestimation was usually found in agricultural fire estimated by MODIS; therefore, all levels of confidence were used.

5.1.3 MODIS for Thailand

a) Path of MODIS orbit over Thailand

Although frequency of Terra and Aqua passing over Thailand is 4 times/day and resolution size can cover Thailand, the 4 images/day does not cover all part of Thailand. Satellite will pass close to Thailand every 2-3 days and pass center of Thailand every 7-9 days, which can be seen in Appendix D.

The Considered schedule of Aqua passed over Thailand in December, 2009 because during this time field experiments were conducted. Aqua satellite passed over center of Thailand on December 1, 8, 17, and 24 in year 2009, which was expected to have full view of Thailand during these days. MODIS span was roughly 1,150 kilometers. A snapshot image of MODIS can cover Thailand for the whole country. During the day that orbit passed at center of Thailand, it was expected that all images cover the whole part of Thailand. Images of December 2, 2009 the day that Aqua did not pass over Thailand are selected to consider (Appendix D). The image confirmed information that Aqua did not pass over Thailand but took image by adjusting angle of the sensor. However, the image cannot cover the whole part of Thailand. On the same date, Terra images cover whole area of Thailand, so only data of Terra was available on that date.

b) Schedule of MODIS passing over Thailand

Reported time of MOD14 data is Greenwich Mean Time (GMT) so +7 hr is required for local Thai time. Schedule of MODIS fly over Thailand in local time was considered by data analysis during 2005-2010. During 2005-2006 (Jan-June), fire hot spot data is obtained from Maryland University, after that data is provided by GIC-AIT. Summary of MODIS schedule is presented in Appendix D.

MODIS fire hot spot data is selected to assess agricultural burned area because frequency is high enough to be able to detect the fire. Agricultural fire in Thailand does not go on for days. Open burning of agricultural residues in rice, corn, and sugarcane field takes around 1 hour. Rice and corn residues are usually burned during day time at 10:00-17:00 from questionnaire (PCD, 2007) and field survey of this study. Sugarcane field is burned during night time at 19:00-22:00 from questionnaire (PCD, 2007) and field survey of this study. Therefore, MODIS has opportunities to detect agricultural fire, except orbit of Aqua that passes over Thailand early in the morning at 1:00-2:00 am.

5.2 Methodology of Burned Area Estimation by Remote Sensing Data

Data for burned area estimation consists of MODIS fire hotspot data (MOD14) (GIC-AIT, 2008), Land use data of rice corn and sugarcane in Thailand (LDD, 2007), and Political

map (LDD, 2002). Summary of methodology for estimating agricultural burned area by remote sensing data is presented in Appendix D.

5.2.1 Data Preparation

Annual MOD14 data was prepared in dbf form by Excel 2003 for input in ArcGIS program. Then Landuse data 2007 was classified into rice, corn, and sugarcane separately by ArcGIS9.2. After that Political Map was prepared in form of provincial information.

5.2.2 Data Processing

The input data (fire hot spot, landuse, and political map) was overlay in ArcGIS9.2 program. Then fire hot spot data was clipped separately on rice, corn, and sugarcane field to obtain fire hot spot on rice, fire hot spot on corn, and fire hot spot on sugarcane area. All detection confidence of hot spot data is used in this study because the false alarm is improved by landuse data clipped out. After that, each result was separated in monthly, to assess temporal distribution of agricultural open burning in each month. Number of monthly fire hot spot in paddy field, corn field, and sugarcane field was used for estimating burned area by 1 hotspot was represented for one fire in an agricultural crop plot area. To quantify burned area, agricultural harvested data per one farmer was multiplied with number of fire hot spot. Area burned is obtained by number of fire hot spot data and harvested area as following

$$A_B = FHS \times A_H \qquad \text{Equation 5.1}$$

where, A_B is Burned area, FHS is number of fire hotspot on rice/corn/sugarcane field, A_H means harvested area per crop plot. Although on fire hotspot grid size is 1 km^2. The 1 km^2 area size does not represent real situation in Thailand because one crop plot size is 3.39±1.19 ha in every part of Thailand, except southern region (1.71±0.35 ha).

5.2.3 Results of Burned Area by Remote Sensing Data

Results of burned area are presented in spatial and temporal distribution by monthly map of fire hot spot on rice, corn, and sugarcane area. The monthly map can present spatial

distribution or location of open burning. Temporal information is described by season, which is determined monthly; that can provide information of major and second rice open burning.

FHS on paddy field was mainly found in central region of Thailand all the year because water resource was irrigation that can cultivate and harvest thoughout the year. In northern and northeastern regions, FHS was found in January-April and December, which are dry season of Thailand in which major rice was harvested. Few FHS was found in southern part of Thailand. Paddy field open burning in south can be neglected when compare with other regions of Thailand. Monthly fire hotspot number is analyzed and presented in Figure 5.1.

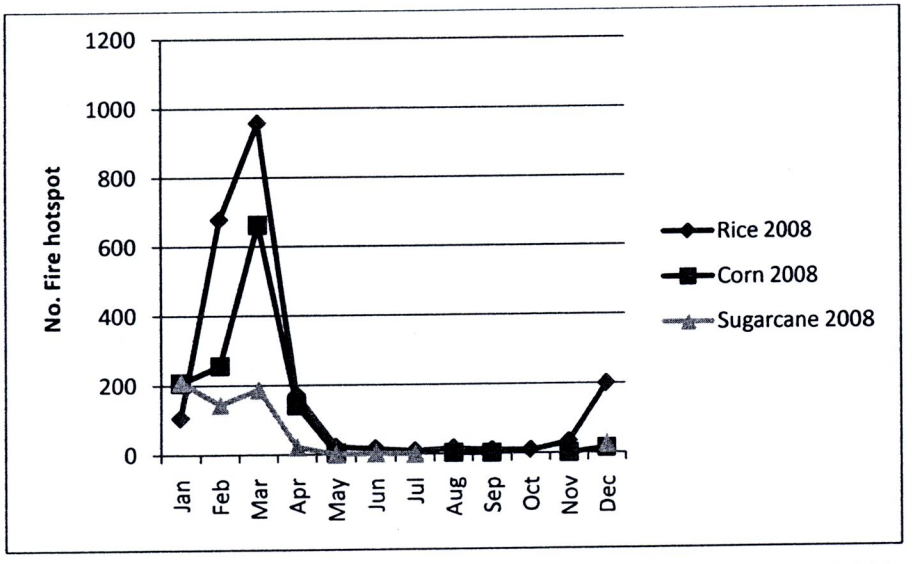

Figure 5.1 Monthly fire hotspot number in rice, corn, and sugarcane field in 2008.

All agricultural fire number has the same trend which was found increasing in November and reached the highest number in March, which is harvesting season of rice, corn, and sugarcane, and also dry season in Thailand in which the weather is convenient for burning. During this season, the sky is clear so the satellite can detect thermal anomalies-fire well.

In dry season, from December to March is harvesting season of corn and major rice that cultivate in every region of Thailand, except south. Therefore, most corn and paddy field open burning is presented during this period. Operation period of sugarcane factory is end of November to beginning of May, that consistent with sugarcane fires found in sugarcane landuse during the same time.

In rainy season of Thailand from May to October, few agricultural fires can be detected. The reason can be because of few harvesting activities and/or low ability of detection in cloudy weather. There is no harvesting activity in sugarcane field during rainy season because no sugarcane factory operated during this time. After corn field is harvested, crop rotation is cultivated and its residues are also burned in the field to prepare land for corn cultivation. However, corn and rotation crop are sometimes ploughed back into the soil without burning in the field. Open burning of irrigated paddy field can be found in this season. After harvesting second rice, farmer usually removes rice residues by burning in the field, but average number of fire hotspot is 14±5 in paddy filed. Most fires cannot be detected because burning period is short and the satellite may not pass over during the fire, including cloudy weather. Therefore, the burned area during this period should be checked with ground based data.

Crop plot size of rice is 3.36 ha (OAE, 2008), corn is 3.22 ha (OAE, 2008), and sugarcane 3.20 ha (field experiment). The crop plot area size and number of fire hotspot data are applied in Eq. 5.1 to obtain burned area. The largest agricultural burned area is paddy field that is burned for 7,476 ha. The second largest burned area is corn with 4,158 ha. Sugarcane burned area is 1,907 ha.

Open burning in paddy field is found in every month because rice can be cultivated through the year in irrigated area. Corn can be harvested since October but farmer will let the product dry in the field to gain more value. Price of corn in the market will be increased gradually from November to March in the next year. Therefore, corn is harvested mainly in January – March to get good price in the market and from low moisture production (usually 14.5% based). Harvesting of sugarcane depends on operation period of sugar factory, which is from November – May. The results show open burning in sugarcane in January-July and December. However, sugar factory is closed from May, so open burning in June and July should be from post harvest burning. Farmer can switch between corn and sugarcane planting in the same area; usually it depends on market price and government promotion. Therefore, the results should be checked with ground based data, which is described as the following.

Underestimate of burned area by MODIS can be for following reasons. Agricultural open burning in the field, crop plot size 1.60 ha takes around 1 hr period from field experiments which are short period that the satellite may not pass over during that time. Period

of MODIS passes over Thailand is 5 min, if the Terra or Aqua satellite does not pass over Thailand during burning; the fire cannot be detected and has an under-estimated result. MODIS Terra and Aqua orbit passes nearby Thailand every 2-3 days, so satellite image reach some part of Thailand every 2-3 days. MODIS Terra and Aqua orbit passes center of Thailand every 7-9 days but alternate between Terra and Aqua.

5.3 Ground Based Data

5.3.1 Ground Based Data for Estimating Burned Area

Ground based data that can provide burned area consists of agricultural statistical data (OAE, 2008), literature review of burned area percentage (PCD, 2007; Penwadee, 2010), and factory information (OCSB, 2008), which is presented in Table 5.1.

Table 5.1 Ground based data for estimating burned area

No.	Information	Source
1)	Agricultural statistic data of Thailand: harvested area and production of rice, corn, and sugarcane	OAE, 2008
2)	Burned area percentage of rice, corn, and sugarcane	PCD, 2007;
3)	Burned area percentage of rice	Penwadee, 2010
4)	Statistic data of sugarcane: harvested area for production sell to sugar factory, amount of burned cane sell to sugar factory	OCSB, 2008

Note:

1) Annual agricultural statistic data was obtained by questionnaire that was distributed throughout the country by government of Thailand and analyzed by statistical method.

2) Burned area percentage of rice, corn, and sugarcane was obtained by interview representative farmers in each region of Thailand.

3) Burned area percentage of rice was obtained by interview representative farmers in each region of Thailand and field survey to check the information.

4) Sugarcane statistic data was obtained by digital data from SPOT and ALOS satellite during March 2007-March 2008 cover 47 provinces that cultivate sugarcane, database of OCSB, and ground survey information from sugarcane industry in each region.

National agricultural statistic data of major rice, second rice, maize, and industrial sugarcane consists of planted area, harvested area, production, yield, farm price, and farm value. Harvested area is usually less than planted are due to crop damage i.e. flood, drought etc. (OAE, 2008).

Agricultural burned area information from PCD report consists of burned percentage 15% corn, 50% major rice, 75% second rice, 50% sugarcane harvest in Thailand (PCD, 2007). Open burning in paddy field has been studied, which is classified by major and second rice and water resource by personal communication with Khun Penwadee Cheewaphongphan from her paper for CTC, 2010 conference and obtained results as followings: Irrigated major rice 1.602 Mha, rain-fed major rice 0.964 Mha, irrigated second rice 1.092 Mha, and rain-fed second rice 0.243 ha, respectively (Penwadee, 2010).

Sugarcane statistic information is provided by Office of the Cane and Sugar Board that sugarcane factories are members and report daily raw material data. Statistics year 2006/2007 means the period of data covers factory opened period since end of November 2006 to beginning of May 2007. Purposes of sugarcane cultivation are for seeding in the next cultivation and selling to sugarcane factory. In this study, area burned was obtained from harvested area of sugarcane product for selling to the factory and fraction of burned product in the sugarcane factory (OCSB, 2008).

5.3.2 Methodology for Burned Area Assessment by Ground Based Data

The ground based data was used to quantify burned area in rice, corn, and sugarcane field as followings.

$$A_B = B\,(\%) \times A_h \qquad \text{Equation 5.2}$$

where, A_B is Burned area, $B(\%)$ is fraction of burned area in percentage (%) and A_h is harvested area of each crop type and/or specific area according to %burn information. Calculation of burned area in sugarcane field is obtained by

$$A_B = (P_{dB}/P_d) \times A_h \qquad \text{Equation 5.3}$$

$$P_d = (P_{wB}+P_w) \times \%dm \qquad \text{Equation 5.4}$$

$$P_{dB} = P_{wB} \times \%dm \qquad \text{Equation 5.5}$$

where, P_{dB} and P_{wB} is burned product dry and wet basis weight (ton/y), P_d and P_w is total product dry and wet basis weight (ton/y), $\%dm$ is percentage of dry matter obtained by moisture analysis, however this value is gone in Eq. 5.3. A_h is harvested area of sugarcane to the factory.

5.3.3 Results of Agricultural Burned Area from Ground Based Data

a) Rice

a.1) Agricultural harvested area (OAE, 2008) and Percentage of burned area (PCD, 2007)

Results of burned area in paddy field based on national agricultural statistics and (OAE, 2008) national report (PCD, 2007) are presented in Appendix D. The major and second rice burned area in each region of Thailand is analyzed. Burned area of major rice was found mainly in northeast region of Thailand, while second rice was found in central. Statistic of burned area in major rice is stable since 2005; however, burned area in second rice tends to increase annually, especially in north. Burned area of paddy field in south is so small when compared with other regions of Thailand. Statistic burned area of major rice is quite stable, except in 2002. The paddy field was flooded for 960,000 ha so burned area was low in 2002. Burned area of second rice tends to increase gradually since 2000 because of improving technology that rice can be cultivated many times in a year.

a.2) Paddy field burned area (Penwadee, 2010)

Major and second rice can be classified by water resource into irrigated and rain-fed area. Irrigated areas receive water from irrigation so cultivation can be done 2-4 times a year. Rain-fed area usually cultivates rice 1-2 time(s)/year. Burned area in rain-fed and irrigated paddy field was studied by questionnaire and field survey (Penwadee, 2010). Irrigated paddy field is the largest burned area in both major and second rice because farmer would like to prepare land for the next rotation quickly, so burning is the most convenient and cheapest way to remove rice residues out of the field. In rain-fed area, water resource is not enough to cultivate the second time, so few areas were found to be burned in rain-fed second rice.

b) Corn

The information of burned area in corn field is available from one source, which is national agricultural statistic data (OAE, 2008) and percentage of burned fraction (PCD, 2007). From field survey in this study was found that corn residues were usually ploughed back into the soil and the report of PCD (2007) found 15% of corn residues were burned in the field by bending the corn tree down to make continued fuel before burning, which require labor. Open burning in corn area is quite small when compared with burning in rice field. Total area burned of corn is 139,000 ha, which is smaller than the smallest burned area of rice, second rain-fed rice field that burn for 243,000 ha.

Regions of Thailand where burning of corn can be found are north, northeast, and central plain, because other regions are not suitable for corn cultivation. The largest corn burned area is found in northern region of Thailand. Ratio of burned area in north, northeast, and central plain is not changed by time during 2005-2007. Trend of burned area in corn field is decreased gradually since 1998 according to reducing of corn harvested area (OAE, 2008). Corn and sugarcane can be cultivated in the same area. Land use changes from corn field to become sugarcane field because of market price and government promotion in renewable energy. Therefore, burned area of corn tends to decrease annually.

c) Sugarcane

Sources of burned areas in sugarcane field consist of national agricultural statistic (OAE, 2008), national report (PCD, 2007), and sugar factory group (OCSB, 2008). Results of sugarcane area burned are followings.

1) Agricultural harvested area (OAE, 2008) and Percentage of burned area (PCD, 2007)

Half of sugarcane harvested area is burned for 505, 000 ha. Sugarcane burned areas are located in north, northeast and central plain of Thailand, which distribute almost equally through the country. Sugarcane burned area in northern and central does not changed by time but increasing sugarcane burned area is found in northeastern part of Thailand, where bio-ethanol factory is located. Trend of burned area is increased in a loop by decreasing from 1999 to 2001 then increase in 2002 and 2003, after that decrease again in 2004-206, and increase until present. However, the whole picture of sugarcane burning is increasing because of government promotion in renewable energy.

2) Office of the Cane and Sugar Board

Total sugarcane burned area is 613,889 ha During November 2006 – May 2007, which is higher than national statistic data 505,140 ha in the same agricultural year. The sugarcane factory statistic data is more reliable because of more detail in cultivated area separate for seeding and selling, %burned product in each factory, and update data every year by remote sensing and field survey method. The region is classified into 4 regions; East is included in Center in national agricultural statistics. There is no detail of sugarcane cultivated area for factory in the year before 2007. Trend and fraction of each region is the same as national statistical data that burned area is increasing and main region of sugarcane burned area is northeastern part of Thailand. Sugarcane burned area in northeast tends to increase higher than other regions because of demand in raw material for renewable energy.

5.4 Analysis of Agricultural Burned Area in Thailand

Based on year of comparison between burned area results from remote sensing and ground based data is 2007 because of agricultural practice available until year 2007. Agricultural statistic data is available in agricultural year so year 2007 is available by agricultural year 2006/2007. Major Rice 2006/2007 means rice that cultivates during May 1, 2007 to October 31, 2007, which is harvested during August 2006 to April 2007 because cultivation period is around 90-180 days from field survey. Second rice means rice that cultivates in dry season or off rainy season during November 1, 2006 to April 30, 2007, which is harvested during February 2007 to August 2007 because cultivation period is 80-120 days from field survey. Planting period of industrial corn is May 1 to April 30 and harvest during August 2006 to June 2007. Industrial sugarcane is sugarcane that harvested for selling to sugar factory during October 1, 2006 to May 31, 2007.

Agricultural burned area results from both ground based and remote sensing based are summarized in Table 5.2, which consist of rice, corn, and sugarcane burned area results from national statistic data (OAE, 2008 and PCD, 2007), and remote sensing data (MOD14, GIC-AIT, 2008); sugarcane burned area from sugar factory data (OCSB, 2008); and rice burned area from research data (Penwadee, 2010).

Table 5.2 Agricultural burned area results 2007

Crop type	National statistic data (1,000 ha)	Remote sensing data (1,000 ha)	Sugar Factory data (1,000 ha)	Research data (1,000 ha)
Rice	5,515	17	-	**3,901**
Corn	**139**	6	-	-
Sugarcane	527	3	**614**	-

Note: National statistic data (OAE, 2008 and PCD, 2007), Remote sensing data (MODIS), Sugar Factory data (OCSB, 2008), and Research data (Penwadee, 2010)

These two approaches of remote sensing and ground based should be combined together to estimate burned area because the remote sensing data can explain spatial distribution of agricultural fire in each month; however, it cannot quantify burned area, while statistical data can define size of harvested area in rice, corn, and sugarcane field.

The most reliable data is the source that provides more detail of specific area and reliable method to obtain the data. For rice burned area, Penwadee and Savitri (2010) data is the most reliable source because the data provide information of major and second rice in each region, and more detail in irrigated and rain-fed area by field survey and interview using questionnaire to each region of Thailand. Therefore, paddy burned area is 3,901,301 ha. The remote sensing data is 16,709 ha, which is 234 times less than ground based data or 0.43% of ground based data.

The study of corn burned area is scarce. There is only one source of corn burned area from national statistic data which is 139,125 ha. The remote sensing data of open burning in corn field is 5,877 ha lower than ground based data for 24 times or 4.22% of ground based data.

National statistic data and sugar factory data are quite consistent. The most reliable data is from sugar factory because the data provide detail of burned product in each factory, which is reliable because the data is updated daily by the sugar factory. The cultivated area is obtained by remote sensing data and ground check. The data is classified into cultivated area

for seeding and selling to the sugar factory clearly. Although, the data does not include after harvesting burning, the data is still acceptable because after harvesting burning is for preparing land for a new seeding which is once in three years so it can be neglected. Thus, sugarcane burned area is 597,812 ha that is higher than remote sensing for 224 times (2,739 ha, or 0.45% of ground based data).

5.5 Conclusions

1) Agricultural burned area in Thailand 2007 was estimated by remote sensing (fire hot spot data) and ground based methods in this study. Results of remote sensing based method are under estimated because of short agricultural burning period, and orbit of Terra and Aqua satellite. However, the remote sensing based results agree well with agricultural burning practice in each month. Suggestion of agricultural burned area by satellite data is considered in a small area with high resolution data.

2) From ground based study, paddy burned area was 3,901,301 ha (38% of harvested area), corn burned area was 139,125 ha (15% of harvested area), sugarcane burned area was 597,812 ha (59% of harvested area) in Thailand 2007 (harvested corn OAE, 2008; % burned corn PCD, 2007; burned paddy area Penwadee and Savitri, 2010; harvested and %burned sugarcane OCSB, 2008).

3) Agricultural burned area varies in each year because calculation based on harvested area of each crop type. Percentage of burned area in sugarcane is also changed in each year because the data based on percentage of burned product from sugar factory.