CHAPTER 3
AGRICULTURAL BIOMASS QUANTIFICATION

Biomass assessment methodology of agricultural residues is described in this study. There is no standard method of the biomass assessment methodology, but there is some suggestion to quantify biomass for bioenergy in open method for woody and non-woody biomass (Calle, et al., 2007). The unit of biomass load (BL) is g/m^2; however, biomass collection directly in 1 m^2 cannot represent average value of total agricultural residues in traditional crop plot. Suitable methodology to quantify agricultural biomass is explained as follows.

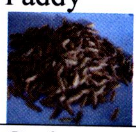
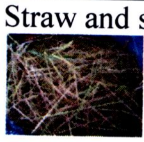
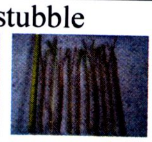
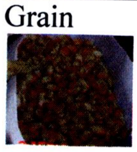
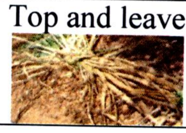
3.1 Definition

The unit of weight in this study is dry mass reference. The sample has been weighed after being placed in a 70°C oven for at least 24 hr until the weight became stable.

3.1.1 Biomass Load

In this study, biomass load is amount of above ground biomass in dry matter basis per harvested area (g/m^2). Biomass residues of each crop type are presented in Table 3.1.

Table 3.1 Definition of biomass from agricultural crop

Crop type	Above ground biomass	Product	Residues
Rice	Paddy, straw, and stubble	Paddy 	Straw and stubble  
Corn	Grain, cob, envelope, leaves, and stem	Grain 	Envelope, leaves, and stem 
Sugarcane	Stem, top, and leaves	Stem 	Top and leaves 

Biomass residues of rice consist of straw and stubble. Straw is the top part of rice that is cut by harvester (machine or human). Stubble is the bottom part of rice after harvesting that is close to the ground. The product of rice is grain. The part of rice residues that are usually burned in the field consists of straw and stubble. After burning, most of the straw is burned and some part of stubble is left and ploughed back into the soil.

Corn residues consist of leaves, stem, and envelope that remain in the field after harvesting. Grain and cob are moved out for utilization. However, the considered product in this study is only grain. Burning of corn residues is done after harvesting immediately because corn residues are dried naturally in the field to reduce moisture in production. All parts are burned but the stem is usually left after burning.

Above ground biomass of sugarcane consists of stem, leaves, and top. The stem is product of sugarcane. The leaves and the top are residues. Open burning in the sugarcane field is done before harvesting to remove sharp leaves that cause injury to harvesters. Therefore, the major part of what is burned is leaves. After that, harvesting is done by cutting the stem above ground. So, both stem and top are moved out. Usually, sugarcane leaves are cut and left on the ground without burning, because burning reduces production value. New sugarcane will grow from the previous seeding called ratoon. After 2-3 ratoons, land will be cleared for a new seeding by burning post harvest. Pre-harvest burn is not satisfactory for farmers because burned cane is a lower price than fresh cane and has to be transported to the sugar factory soon after harvesting to prevent spoiled production.

3.1.2 Fraction Burn

Fraction burn is biomass that remains in the field after utilization. However, the burned field is usually not utilizing the residues so total amount of biomass remains in the field. Therefore, fraction burn is 100% in burned area.

3.1.3 Combustion Efficiency

Combustion efficiency is part of residues that is really burned in the field, which is obtained from quantity of biomass before and after burning, calculated by

$$CE = \frac{\lfloor B_{before} - B_{after} \rfloor \times 100}{B_{before}}$$ Equation 3.1

CE is combustion efficiency (%). B_{before} is biomass weight before burning obtained from field experiment after harvesting (g/m^2). B_{after} is unburned biomass weight that remains after burning (g/m^2).

3.1.4 Residue to Product Ratio

Residue to Product Ratio (RPR) is amount of biomass load per production. Biomass load results from field experiments and production from field survey - used for calculating RPR, which calculations are determined as follows.

$$RPR = residues/production$$ Equation 3.2

where residues and production are in unit g/m^2. Definition of residues and production is presented in Table 3.1.

3.2 Methodology of Biomass Load Assessment

In each experiment site, biomass sampling was done for at least three samples. In paddy field, an experiment site consists of many experiment crop plots. At least two replicates were sampling in each rice crop plot.

3.2.1 Sampling Area

In order to obtain a representative of biomass sample in each crop plot, size of a sampling area is considered by harvested practice. Sampling area size is presented in Table 3.2.

Table 3.2 Sampling area

Crop type	Sampling area
Rice	Straw 1×2 m^2 Stubble 50×50 cm^2
Corn	Corn residues 2×2 m^2
Sugarcane	Sugarcane top, leaves, and stem 2×2 m^2

Rice was cultivated by broadcast so they were homogeneous through the field. Production was harvested by a machine. The machine cut upper part of rice and spread rice straw in windrows for 100±20 cm width. Therefore, rice straw was sampling in 1×2 m^2 to cover row and between rows.

Corn and sugarcane were harvested manually. Before burning, biomass was standing in the field in rows. Sampling area size of corn and sugarcane is 2×2 m^2 to cover two rows of biomass.

3.2.2 Collecting Method

a) Rice: rice straw was collected and stored in a bag. Then rice stubble was cut by a sickle at ground level and stored in another bag. Number of stubble was counted and length of stubble was measured.

b) Maize: Total height of corn tree was measured. The biomass was cut at ground level by knife and stored in a bag.

c) Sugarcane: The sugarcane was cut at ground level by knife and moved out of the field to measure height. Then the samples were separated into top, leaves, and stem. Sugarcane leaves characteristic is different from top because leaves are brownish and dry, but top is green and contains high moisture content.

After collection, wet weight of biomass samples were measured at the field. Then the samples were brought back to consider dry weight, ultimate, and proximate analysis. The biomass was dried by air and sun naturally to reserve for chamber experiments.

3.3 Field Experiments

In order to quantify BL, FB, CE, RPR, and measure emission concentration of $PM_{2.5}$, BC, CO, and CO_2 from combustion of agricultural residues, field experiments were conducted during harvesting period of rice, corn, and sugarcane in 2007-2010. The studied area was selected from major cultivated areas in Thailand that could be representative and was not located in an area hard to access. Paddy fields were classified into irrigated and rain-fed areas by water resource for cultivation. Sugarcane and corn were located in rain-fed areas. Summary of field experiment date and location are presented in Appendix B.

Field experiments were conducted in rain-fed rice field at Amphoe Chombueng Ratchaburi, Amphoe Thatako Nakhonsawan, and Amphoe Mueang Nakhonsawan; and irrigated rice field at Amphoe Kratumbaen Samutsakhon and Phetchaburi. Studied sites of rain-fed corn field are located at Amphoe Takfa Nakhonsawan, Amphoe Pakchong Nakhonratchasima, and Suwan Farm Nakhonratchasima. Studied sites of sugarcane field are located at Amphoe Danmakhamtia Kanchanaburi, Amphoe Banbueng Chonburi, and Amphoe Nhong Yai Chonburi. Locations of the studied sites on Thailand map and cultivation practice from farmer interview are summarized in Appendix B.

3.3.1 Experimental Design

Before burning: Meteorological condition and ambient air quality were measured while biomass was sampling.

During burning: Emission concentration was measuring by real time equipments and aerosol was sampled on quartz filter during open burning of agricultural residues. We tried to keep inlet of these equipments in the plume all the time by moving the equipments along the plume. Time was recorded from ignition until the finishing of measurement.

After burning: Ash and unburned samples were collected. The coordinates of studied sites were measured by GPS (GARMIN, GPSMAP 60CSx) to obtain information of position and area of the crop plots. Equipments for measuring meteorological condition and emission concentrations are described.

a) Equipments for meteorological condition measurement

The weather station (Lacrosse Technology, model ws1600, USA) consists of equipment for measuring wind speed (range 1-50 m/s), wind direction (scale 22.5°), relative humidity (1-99%), temperature (-40°C to +59.9°C), and pressure (920-1,080 hPa). The weather station (Lacrosse Technology, model ws1600, USA) was installed near the experiment site - for 4-5 m away - to prevent from fire at 2-3 m height by setting N point to the north direction. The meteorological data was recorded manually every minute. Form of the meteorological data record is presented in Appendix B.

b) Emission concentration measurement equipments

Frequency of emission concentration measurement was one second because duration of prescribed burn was short period for 1-3 min.

b.1) $PM_{2.5}$

The $PM_{2.5}$ was measured real time by the TSI Inc. DustTrak 8520. The DustTrak is a portable direct-reading real-time monitor incorporating a light scattering laser photometer. The light emitted from the laser diode is scattered by particles drawn through the unit in a constant stream; the amount of light scattered determines the particle mass concentration, which is based on a calibrated using standard ISO 12103-1, A1 dust (Arizona Road Dust). Resolution of the instrument is ±0.1% or 1μg/m^3 and a detection range of 0.1-10 μm ($PM_{0.1-10}$) (Kingham et al., 2006). This study used the range of $PM_{2.5}$. Data were logged at 1 s intervals.

b.2) Black Carbon

The concentration of BC was measured by micro Aethalometer (Magee Scientific, model AE51, USA). The micro Aethalometer is an instrument that uses optical analysis to determine the mass concentration of Black Carbon particles collected from an air stream passing through a filter, which is presented in Figure 3.1. The light analysis was infra-red 880 nm for BC.

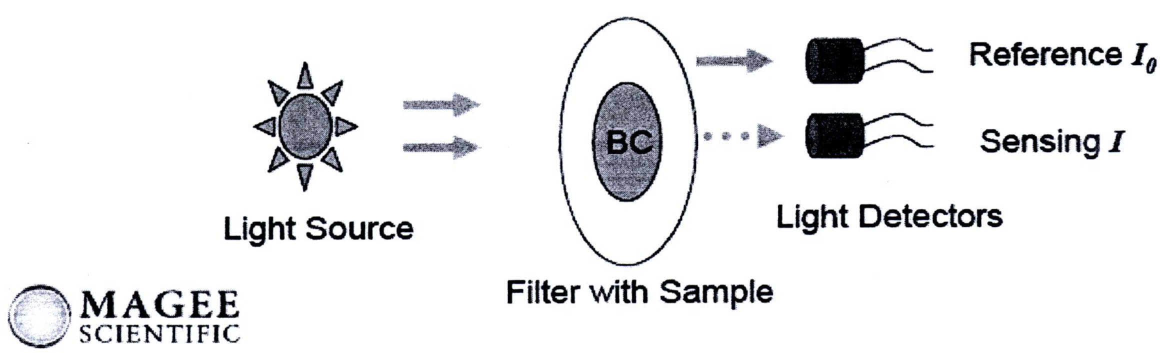


Figure 3.1 Optical Analysis Method of micro Aethalometer. (Hansen, 2009)

The principle is based on Beer's Law: $I = I_0 e^{-(k \cdot D)}$ Equation 3.3

where I_0 is incident intensity; I is transmitted intensity; D is total density of material traversed; k is absorption coefficient (function of wavelength λ). The value of k is known. The I and I_0 values were measured to determine D (amount of absorbing material) (Hansen, 2009).

b.3) CO and CO_2

Measurement of CO_2 concentration was conducted by AQ5000Pro (Quest Technologies, IAQ model AQ5000Pro, USA). The AQ5000Pro is a portable equipment that uses optical analysis to determine the concentration of CO_2 by non-dispersive infrared detector (NDIR) (Quest Technologies, NA). A property of CO_2 molecules is absorbing light at a specific wavelength of 4.26 μm (IR range). High concentrations of CO_2 molecules absorb more light than low concentrations. When gas molecules diffuse into the sensing chamber, the IR light is directed through the sensing chamber towards the detector by using filter that eliminates all wavelengths except IR. Since other gas molecules do not absorb IR, only the CO_2 molecules affect the amount of light reaching the detector. The intensity of light striking the detector is described by Beer's Law in Equation 3.3 (TSI, 2008).

Accuracy of the instrument is ±3% of reading ±50 ppm (0-5,000 ppm) and ±3% of reading ±300 ppm (0-20,000 ppm). Resolution of the instrument is 1 ppm (10 ppm above 10,000 ppm). This study uses detection range 0-20,000 ppm because maximum CO_2 concentration from agricultural open burning over 5,000 ppm. Data were recorded at 1 s intervals. The AQ5000Pro can also detect CO (resolution 0.1, 0.5, or 1 ppm depending on sensor in use), RH (range 0-100%, accuracy ±3% at 25°C, resolution 0.1%), temperature (range 0-60 °C, accuracy±0.5 °C, resolution 0.1 °C), and dew point (range -65°C to +60°C resolution 0.1 °C) (Quest Technologies, NA).

c) Aerosol sampling

The $PM_{2.5}$ and PM_{10} (particulate matter less than 2.5 μm and 10 μm aerodynamic diameter respectively) were collected by operating a portable pump (A.P. BUCK, model VSS-12, USA), operated at a flow rate of 10 L/min. The Aerosol was sampling through pre-combusted (at 650°C for 12 h) quartz filters (PALLFLEX™; size Ø47 mm, USA). Aerosol sampling was carried out during open burning experiment since ignition to extinguishing.

3.3.2 Rice

a) Samutsakhon

a.1) General information

Samutsakhon province is located at the mouth of the Tha Chin River, 30 km from Bangkok. Studied site is located at Krathum Baen District at 47P UTM 638,430x, 1,507,153y. Field experiments were conducted on 25/12/07, 30/06/08, 18/11/08 and 15/09/09. Samutsakhon was in irrigated area that water resource transfers to the paddy field by water channel. Experiments on 25/12/07 and 18/11/08 were conducted in dry season and classified as major rice. Experiments on 30/06/08 and 15/09/09 were in wet season and classified as second rice. On 30/06/08, some areas of crop plot were flooded so the experiment avoided from the wet areas; however, the BL result was lower than other experiments. On 15/09/09, there were rain showers during experiment. During wet season, second rice was cultivated for 105 days in 2008 and 130 days in 2009, which is a longer period than dry season for 80 days in 2007 and 2008. The surroundings are residences and factory, which can be seen in Figure 3.2.

a) b)

Figure 3.2 Surroundings of studied site in Samutsakhon: a) residence and b) factory.

From Figure 3.2, residences and factories are located in surrounding area, including a small street, which burning of rice residues in this area can make annoyance to people. Rice cultivated area in this province is "irrigated low land" rice that cultivated for 2-3 times a year.

a.2) Biomass sampling

The biomass was sampling from all plots for two experiments (25/12/07 and 30/06/08) and focused mainly in burned plot, SS_BL and SS_BM, for last two experiments (18/11/08 and 15/09/09). The first experiment (25/12/07), rice residues was sampling in 1m×1m from in row, half row and between rows, and between rows. However, the results cannot represent biomass for the whole plot. Therefore, we improved the collection method in the second and the third experiment (30/06/08 and 18/11/08) by collecting biomass in row for 2 samples and between rows for 2 samples in each crop plot. However, the BL results contained high uncertainty because of difference between in row and between rows results. The last experiment (15/09/09), rice straw was collected in 2m×2m area to cover row and between rows. However, high amount of straw could not store in one bag so suitable size of sampling area was suggested as 1m×2m.

Rice type of this experiment site was one of short period species (80-120 days), so height of biomass above ground is lower than long period rice species (180 days), i.e. Lueang Chum Pon at Ratchaburi ~90-100 cm.

a.3) GPS measurement

Studied crop plots were divided into 6 plots consisting of 4 small plots and 2 large plots. Width and length of four small plots were 15m×60m size, and two large plots were 20m×70m size. Detail of crop plot areas are presented in Table 3.3. Figure of crop plots is presented in Appendix B.

Table 3.3 Area of rice crop plots in Samutsakhon

Crop plot	Area (m^2)	Agricultural practice
SS_SL	900	move straw out and local drainage
SS_BL	879	burn straw after harvesting and local drainage (traditional practice)
SS_SM	875	move straw out and mid season drainage
SS_BM	1,502	burn straw after harvesting and mid season drainage
SS_IM	1,455	incorporate straw back to soil and mid season drainage
SS_IL	861	incorporate straw back to soil and local drainage

Note: Agricultural practice of crop plots was designed by Tassanee (JGSEE Ph.D. student)

a.4) Open burning experiment

Open burning field experiments were conducted on 27/12/2007, 07/07/2008, 20/11/2008, and 17/09/2009. The difference among these experiments was rice type, season, and emission concentration measurement parameter. The 2nd and 4th experiments were conducted in rainy season.

i) The 1st experiment was conducted after harvesting for two days (harvested on 25/12/07 and burned on 27/12/07). The rice residues were in dry condition.

ii) The 2nd experiment was conducted after harvesting for one week (harvested on 30/06/08 and burned on 07/07/08). On the date that straw was burned, climate was quite humid because there was heavy rain before that time so some area in the paddy field was flooded. Moreover, there were rain showers during the burning of the whole SS_BL. Traditional burn was usually done in the afternoon when straw was dried and calm wind was presented. However, we conducted burning at 10.00 am because it was going to rain at that time, we could not wait to do burning in the afternoon. Ten field experiments consisted of 4 experiments for 1×1 m^2 at crop plot BL and BM, and 2 experiments for traditional burning at crop plot BL and BM.

iii) The 3rd experiment, rice residues were burned on November 20, 2008, after harvesting for two days. The prescribed burn was conducted to measure emission concentration of rice residue burning in 1×1 m^2 for 2 replicate at SS_BL, 2 replicate at SS_BM, and traditional burn at both plots. Field experiment was during 14:42 to 18:16.

iv) The 4th experiment rice residue was burned on September 17, 2009, during afternoon after harvesting for two days. The prescribed burn was conducted in 1×1 m^2 for 2 experiments at SS_BL, 2 experiments at SS_BM, and traditional burn at SS_BL.

The first two experiment dates in Samutsakhon were conducted by using bamboo wood around 2.5 m height to install aerosol sampling and measurement equipments, which is presented in Figure 3.3.

a) Traditional burn b) 1m×1m burn

Figure 3.3 Open burning experiment at the irrigated rice field in Samutsakhon (07/07/2008).

But this method caused damage to the equipment because of too high temperature. There was an error in the results i.e. CO_2 concentration was over the maximum concentration detection. Therefore, the suitable method is installing the measurement equipments on the same stand with inlet of all equipments stay closed, so the same air mass input into all equipments. The appropriate method for measuring emission concentration is presented in Figure 3.4.

Figure 3.4 Open burning experiment at the irrigated rice field in Samutsakhon (17/09/2009).

Therefore, all parameters were measured by using the same stand to sample the same air mass of the plume. At this site, traditional straw burning was done in the field when calm wind was presented to control fire and prevent smoke from disturbing transportation on a local road and residences, usually in the afternoon after dew evaporated (10:00-16:00). Burning period was around 1 hr/plot (1.6 ha).

From prescribed burning, all emission concentration results showed the same trend that increased in the initial phase and decreased after reaching the maximum peak. High moisture content in wet season caused difficulty in combustion and presented low emission concentration.

Traditional burning was carried out to measure real burning practice in the field. Ignition was done by the farmer at many points in order to burn continuously. The equipments were kept in the plume all the time but the smoke was quite harmful to eyes and respiration system, so the equipment was left at a position in the plume. When the plume direction was changed, the equipment was moved to another position to keep position in the plume until the fire was extinguished. High variation of $PM_{2.5}$ was found in traditional burning experiment because burning was continuously done in a large plot that had many surrounding influences, especially meteorological conditions and topography.

b) Nakhonsawan

b.1) General Information

Nakhonsawan province is located in lower northern part of Thailand. Field experiment was conducted on 14/12/08 and 29/12/09 at Amphoe Thatako and 20/09/09 at Amphoe Mueang.

i) Amphoe Thatako

Two experiments were conducted on 14/12/08 and 29/12/09, with different crop plots but in the same area.

The first experiment (14/12/08) was located at 47P UTM 662,726E, 1,731,541N. Size of the studied plot was 3.2 ha, where many plots (belong to different farmers) were connected in the same area, and separated by soil mound. Every plots cultivated same the type of rice and the same method, so dried plots were selected to determine biomass amount and emission concentration because it was flooded in some area. Size of each crop plot was around 80m×110m, which north crop plot is 8,800 m^2 and south crop plot is 10,100 m^2, respectively. The rice Khao-Dok-Mali-105 - photoperiod sensitive varieties – was cultivated once a year by the broadcast method. Duration of each batch was 180 days (July to December 5, 2008). Straw was dried naturally in the field. There was no alternative crop during break of cultivation.

The second experiment (29/12/09) was located at N15.69821, E100.52836. Rice type was C85. The paddy fields, belonging to many owners, were separated into around 1.6 ha per plot. Each plot is nearly the same size, with 70 m width and 200 m length. Area size of crop plot from the east is 14,600 m^2, 12,500 m^2, and 17,500 m^2, respectively. Harvesting was done by using machine; however, height of stubble that was left on the ground after harvesting was different among three plots. Stubble height in plot 1 was the shortest, 12.5±2.5 cm, plot 2 was 27.5±2.5 cm, and plot 3 was 21.5±1.5 cm, respectively. Straw was dried naturally in the field. The field experiment was conducted in three crop plots in order to obtain BL and emission concentration from traditional burn.

ii) Amphoe Mueang

Studied plot of paddy field is located at 47P UTM 609,354x, 1,735,215y. Many crop plots were connected in the same area, and separated by soil mound. Every plot cultivated same type of rice and same method, so dried plots were selected to determine biomass amount and emission concentration because there was heavy rain in this area before experiment for 2 days. But it was sunny on date of experiment (20/09/09). Natural pond and rain were the major water resources for paddy cultivation in this area. Area size of each crop plot from north was 50m×105m (5,250 m^2), and 40m×105m (3,960 m^2). Rice type was Supanburi 3. The rice was cultivated twice a year by broadcast method. Duration of each batch was 75 days in previous cycle (type C75) and 120 days in this cycle. Straw was dried naturally in the field. The field experiment was conducted in two crop plots. Soil condition was flooded for 2-3 cm but strong solar radiation on the experiment date, so upper part (straw) was dried but lower part (soil and stubble) was wet.

b.2) Biomass sampling

Experiments on 14/12/08 and 20/09/09, biomass collection was carried out in 1m×1m in row. However, the result cannot represent average value of total agricultural residues in traditional crop plot. The last experiment on 29/12/09, rice straw was collected in 1m×2m area to cover row and between rows. The BL results can represent average value of total agricultural residues in traditional crop plot. Stubble was collected for 50×50 cm^2 to measure weight, height, and number of stem. Biomass load results of rice straw in Nakhonsawan are presented in Appendix B.

From the results, it was found that although rice type of experiment 1 and 2 was the same, BL was different because of cultivation being in different places (Amphoe Thatako and Amphoe Mueang). Another finding was larger BL in rain-fed rice when compared with irrigated rice that was cultivated in a shorter period.

b.3) Open burning experiment

The experiments of open burning were conducted at rain-fed paddy field in Nakhonsawan on 14/12/2008, 20/09/2009, and 29/12/2009. Difference among these experiments is rice type, location, and measurement parameter. The first and the third experiment were carried out in Amphoe Thatako but different crop plots and different rice type. The second experiment was conducted in Amphoe Mueang.

i) The 1st experiment on 14/12/2008, only prescribed burn in 1m×1m was conducted for four replicates because other fields were not harvested, so fire might damage their production. The wind was quite strong for 1-2 m/s during the open burning experiment so the fire was high and the smoke was blown horizontally above the plume because the wind blocked the plume at the top of the fire.

Concentration of CO_2 was presented at the initial phase, where complete combustion or flaming was dominant. After that, when smoldering is dominant, CO is increased and reached maximum then decreased until the fire was extinguished. Concentration of $PM_{2.5}$ is present when smoldering is dominant, which is consistent with CO graph that increases and decease at the same time.

ii) The second experiment (20/09/09) was carried out by prescribed burn in 1m×1m for four replicates and a traditional burn for one experiment. There was heavy rain in this area before burning for 2 days, but it was sunny on the experimental date. The area was flooded around 2-3 cm; however, straw was dried by strong solar radiation. The water level was enough for fish to survive; however, temperature of water was increased until fish could not survive. The wind was calm (0-1 m/s) during the open burning experiment so the fire was high and the smoke rose up to the sky for around >100 m. However, we could not access the rising plume because the equipment was located at one side of the plot.

iii) The third experiment was conducted by traditional burns for three replicate during 14:30 to 17:00 on December 29, 2009. Area size was 1.6 ha/plot, which took 60±20 min since ignition to distinguish. Traditional ignition was started at downwind to upwind for personal protection of farmers from smoke. This practice was done in the same way as at Samutsakhon's field. Although burning of rice residues was conducted at the same area, emission concentration measurement was located at different positions because of wind direction and wind speed. Low wind speed caused plume to rise into the air, while strong wind blew the plume at ground level into the measurement equipment.

Experiment 1 was conducted in the plot that was located in the middle among two studied plots. During burn, wind direction was across the plot, so monitoring instruments could be located in the plume all the time. Results of the emission concentrations of the 1^{st} experiment are higher than other experiments because the equipments can be kept in the plume nearly all the burning period. Maximum $PM_{2.5}$, CO and CO_2 concentration is double of the other two experiments.

Experiment 2 was conducted in crop plot at the west. During this burning, wind speed was strong but wind direction was changed. Therefore, low emission concentration was detected. Wind speed of the 2^{nd} experiment is the same as the 1^{st} experiment but changed direction so the equipment can follow the plume in a limited area due to topography – so the equipments can sometimes be kept in the plume direction. Therefore, the graph is fluctuated all the time. Air samples are in the same volume, so the graphs are in the same trend among air pollutant concentrations.

Experiment 3 was conducted in crop plot at the east. Calm wind was presented so most plume rose up into the air. Therefore, the lowest emission concentration was found in this experiment. Two periods of strong wind blew the plume to reach the emission concentration measurement equipment. The equipment is out of plume during most of the experiment period because of low wind speed and the plume rose into the air. However, maximum concentration is low when compared with the other two experiments. This experiment does not take into account for EF calculation because of very low concentration.

c) Phetchaburi

c.1) General information

Phetchaburi province is the central region of the country, located 160 km from Bangkok. Overall area of Phetchaburi is 6,225 km^2. The site is located at 47P UTM 588,529E, 1,467,180N in Ban-Nhong-Chumpon Distict. The land was divided into 22 small plots. Two plots (PR-1 and PR-2) were studied by Khun Kalayanee to determine emission load of greenhouse gases from traditional rice cultivation. Area size of PR-1 (north) is 1,600 m^2 and PR-2 (south) is 3,600 m^2. However, cultivation practice was the same between these two plots.

c.2) Biomass sampling

The experiment was conducted on 26/12/2008, before harvesting. Main purpose of field experiment in Phetchaburi was to determine amount of biomass and production. The straw was utilized by packing in rectangular shape by straw baler machine and sold as cow fodder. There was no burning of rice residue in this area so open burning rice residue was not conducted in this studied site. Biomass before harvesting was collected in 30cm×30cm to determine paddy, straw, and stubble quantity.

Rice was cultivated by broadcast method and harvested by machine. This study determined BL to be compared with other results. Farmers cultivate twice a year, rice type of major rice was Lueang-Pa-Tew and second rice was Chinat. Although this area was an irrigated rice field, the cultivation of major rice in this batch was a long period - for 140 days. Farmers applied biological fertilizer to the field in August and October, but did not put any herbicide/pesticide into the field. The production yield was 4,018.75 kg/ha. Baled straw amount of plot PR-1 was 20 packs and PR-2 was 18 packs (18-20 kg/pack). Farmers gained income 20 baht/pack. Some part of the field was flooded by irrigated water that flow in the field before time, so wet straw was left in the field to decay.

Biomass load of straw in Phetchaburi was 604±28 g/m^2, estimated from before harvesting biomass. Information of stubble height was 26±1 cm from field survey. The straw was collected for selling to animal farms by straw baler. RPR of straw was 0.59±0.03.

d) Ratchaburi

d.1) General information

Ratchaburi is located on the bank of the Mae Klong River, 80 km west of Bangkok. Total area of Ratchaburi province is 5,196 km^2, and is divided into nine districts. The studied site is in Chom Bueng district, which is located back of KMUTT campus. Area of crop plot in Ratchaburi was 1.6 ha. The land was divided into many small plots (20m×20m). Four plots were studied by khun Kalyanee to determine suitable straw utilization to reduce greenhouse gases in rain-fed area, which is called RB-B, RB-S, RB-C, and RB-I from south to north. Plot RB-B was burned after harvesting, plot RB-C plowed only stubble back into the field, straw and stubble in plot RB-I were plowed into the field, and plot RB-S was traditional cultivation; that straw was eaten by cows. This study focused on crop plot RB-B; that residue was burned. This area had drought at the initial phase of cultivation. Normally, rice was harvested by machine but this batch of rice was harvested manually and straw was moved out to separate grain manually.

Major rain-fed rice was cultivated once a year and there was no alternative crop while the land was empty. Straw was utilized for cow feeding in the field; therefore, fertilizer was obtained from cow manure. Rice type of this batch was Lueang-Chum-Pon. Cultivation duration was 180 days. However, drought weather during initial phase of seeding resulted in low production in this year. Amount of production in this batch was 0.375 kg/m^2. In order to reduce cost of harvesting, farmers harvested and removed spike to obtain grain manually.

d.2) Biomass sampling

Field experiment was conducted on 11/12/2008. The biomass was collected to determine BL in 30cm×30cm before harvesting. BL is determined by assumed 25 cm stubble height due to manual harvesting by farmer.

Biomass load of rice straw in Ratchaburi is 258±111 g/m^2 estimated from before harvesting residues, approximate 25 cm stubble height. RPR of straw is 0.69±0.30. However, the BL is lower than other rain-fed rice i.e. Nakhonsawan so the BL results from experiment Ratchaburi do not take into account for BL of rain-fed rice residues.

3.3.3 Corn

a) Nakhonsawan

a.1) General information

Nakhonsawan is in the lower northern part of Thailand between the North and the Central Region. Location of studied site is at 47P UTM 663,125E, 1,699,476 N in Takfa district. Total area of studied crop plot is 176,000 m^2. The land was divided to four large plots. Two plots were studied called plot NS-SF and NS-AF. Plot NS-AF was left as after harvesting, corn trees were standing in the field. Plot NS-SF was planted sunflower already so residues were turned down. Crop plots of corn are presented in Figure 3.5.


a) b)

Figure 3.5 Corn field at Amphoe Takfa, Nakhonsawan a) Plot NS-SF: sunflower growing and b) NS-AF: after harvesting.

Corn type that was cultivated in this batch was 919 Cargin Company (previous type was 901). Cultivation duration was 120 days. Farmers cultivated once a year so they grew sunflower after harvesting as an alternative crop. Corn product was harvested by labor. Production (grain and cob) of total area (17.6 ha) was 148.5 ton. Corn residues in this study included leaves, stem, and envelope of product. From field survey, residues of corn and sunflower were ploughed back into the soil. However, sometimes residues were burned. Before experiment, it rained heavily for weeks so soil was soft and wet.

a.2) Biomass sampling

The field experiment was conducted on November 1, 2008 at Amphoe Takfa, Nakhonsawan. Corn residues were collected after harvesting. Distance between rows of corn was 75 cm so the biomass was collected in 1.5×1.5 m^2.

Biomass load of corn residues consist of stem, envelope, and leaves. The corn residues' BL is 520 ± 66 g/m^2 obtained from crop plot AF or standing corn residues. Density of corn is 13 ± 2 $stem/m^2$. However, corn height cannot be measured in this crop plot because of decay from rain-fall.

a.3) Open burning experiment

Prescribed burn was conducted on 01/11/08. Corn residues were left standing in the field so the residues were bent down for 1.5m×1.5m. The fire was ignited at one point. The experiments were carried out for 5 replicates. High moisture content in biomass caused difficulty in combustion in some experiments. The flame was quite strong and less smoke was present. Flaming was dominant in these experiments. Traditional burn of corn residues could not be done because of high moisture content in soil, so farmer would plough the residues back into the soil.

$PM_{2.5}$ was increased from flaming phase and reached maximum or dominance in smoldering phase. Then the concentration of $PM_{2.5}$ was decreased until extinguished. However, flaming was dominant in corn residues open burning so low $PM_{2.5}$ concentration was found when compares with other experiments in paddy field.

b) Pakchong

b.1) General information

The studied site is located in Amphoe Pakchong at 770,497E (UTMx) and 1,606,526N (UTMy), the same province as Suwan Farm, and this field belongs to a local farmer. Area of the studied plot is 26,984 m^2 (150×180 m^2), which is presented in Appendix B.

Corn type was 919, which was planted by machine in July and harvested in January. Normally, duration is 120 days but this crop was harvested late for production drying to gain value. Water resource was rain. Row width was 70 cm and length between seed was 25 cm. Chemical fertilizer was applied when seeding (16-20-0) for 125 kg/ha and flowering (46-0-0) for 312.5 kg/ha.

b.2) Biomass sampling

Field experiment was conducted on January 17, 2010. Corn residues and products were collected before harvesting by cut residues at ground level for area 2×2 m^2 and measured weight then brought back to the laboratory.

Corn residues consist of leaves, stem, and envelope that contain moisture for 6%, 8%, and 5%, respectively. Biomass load result is 651±211 g/m^2. Corn height is 197±8 cm. RPR of corn residues is 1.17. Density of corn is 5.5 stem/m^2.

b.3) Open burning experiment

Prescribed burn was conducted on 17/01/10 after harvesting. Burning could be done immediately after harvesting because production was dried in the field naturally before harvesting for months. Corn residues were bent down for 7m×8m by farmer to set the same condition in the traditional way. Although experiment date was in dry season, traditional burn could not be conducted because harvesting was not finished. Ignition was started at upwind. Emission concentration measurement was carried out at downwind. The corn residues were dried and placed continuously, so combustion efficiency was high, 88%. During the experiment, flaming was strong and also a large quantity of smoke was generated. The graph was quite smooth because the plume reached the equipment nearly all the time, except when wind direction was changed after three minute burning. Maximum concentration was nearly the same as the 1st experiment of traditional rain-fed open burning in Nakhonsawan. When smoldering phase was dominant, it could be significantly noticed that CO and $PM_{2.5}$ would peak nearly the same time after the CO_2 graph that complete combustion was presented.

c) Suwan Farm

c.1) General information

Suwanwajokkasikit Field Corps Research Station or locally called Suwan Farm (the National Corn and Sorghum Research Centre of Kasetsart University) is located at 14.5°N and 101.3°E, 388 m above mean sea level, 155 km northeast of Bangkok at Amphoe Pak Chong, Nakhonratchasima province. Total area is 414 ha, which is separate into two parts by Pang Asoke Mountain. Cultivated area is 171 ha using underground water for irrigation (SWRC, 2010). The farm cultivates both sweet corn for human consumption and corn for animal fodder. In this study, we focus on industrial corn so only biomass of this corn type was considered. Several corn varieties have been developed in this farm and the studied plot was under development so product information was not published. The experiment was conducted in a crop plot size 100m×200m.

Field experiment was conducted on November 28, 2009. Corn was seeding by machine with 75 cm row width, 10 cm distance between seed, and 130 cm width between rows. Chemical fertilizer was applied, but no pesticide or herbicide was applied in the farm. After manually harvesting, residues were ploughed back into soil.

Corn residues consist of top, leaves, stem, and envelope that contain moisture for 5%, 7%, 33%, and 41%, respectively. Average moisture content is 22%. Biomass load of corn residues is 660±94 g/m^2. Density of corn is 11±3 $stem/m^2$. There is no information of product so RPR cannot be estimated.

3.3.4 Sugarcane

a) Kanchanaburi

Kanchanaburi is located in the west of Thailand, around 129 km from Bangkok. The province covers a total area of approximately 19,483 km^2. Sampling site is in Amphoe Dan Makhamtia, which is located in south of Kanchanaburi. Field experiment was conducted on harvested date 03/02/08. Sugarcane type in Kanchanaburi is K88-92, which is the first seeding. Parameters that are considered in field experiment consist of BL, size of crop plot, and cultivation practice. The BL was determined by pre-harvest biomass collection. UTM coordination of sampling site is 535,377E (UTMx) and 1,532,624N (UTMy).

The sugarcane was grown since February 2007 and harvested in February 2008. This harvesting was the first production after seeding. Number of harvested per one seed was three times by harvesting once a year. Water resource was obtained from rainfall. The sugarcane residues were not burned in this area but those were left on the ground to decompose naturally. On the date that we collected the sample, there was one person collecting sugarcane top for animal feeding. However, the utilized quantity was so small, only a small cart. Height of sugarcane was 300 cm. Number of sugarcane was 8 stems per m^2. Row width of sugarcane was 85 cm and space between sugarcane in the same row was 85 cm. The crop plot size was 1.92 ha. Sugarcane was harvested manually by cut at ground level and leaving the top and leaves in the field. From the interview, product was 62.5 ton/ha and sweetness of sugarcane was 10.5-10.8 CCS.

Sugarcane leaves characteristic was quite dry but top of sugarcane was green and contained high moisture. The moisture analysis results were 0% for leaves, 30% for top, and 70% for stem, respectively. Biomass load is sugarcane leaves 1,240±260 g/m^2. Product is dried cane, 3,948 g/m^2 and RPR of leaves is 0.31.

b) Chonburi

Chonburi is located on the eastern coast of the Gulf of Thailand, 80 km from Bangkok. The province is subdivided in 11 districts, which sampling site is in Amphoe Ban Bueng and Nhongyai. Field experiment was conducted three times during harvesting on 29/02/2008 at Amphoe Banbueng, 22/01/2009 at Amphoe Nhongyai, and 23/01/2009 at Amphoe Banbueng. The first experiment, the biomass was sampled in 1.5×1.5 m^2 area. Parameters that were considered in field experiment consisted of BL, RPR, height, and cultivation practice. Biomass load was carried out by pre-harvest biomass collection.

The biomass was conducted before harvesting in 1.5m×1.5m on the 1st experiment data and 2m×2m on the 2nd and 3rd experiment date randomly for 4 replicates. The biomass was cut at ground level then moved out of the field to measure height before separating top, leaves, and stem. Wet weight of pre-harvest biomass was measured at the field. Some samples were brought back to the JGSEE laboratory to analyze for moisture content and elemental analysis.

On 29/02/2008, sampling site location is in Amphoe Banbueng. UTM coordinate of sampling site was recorded by GPS at 742,793E (UTMx) and 1,469,220N (UTMy). Total area is 36.8 ha for one crop plot (300m×1,230m). This plot was divided into many small plots for walking through but cultivated and harvested in the same period.

On 22/01/2009, sampling site location was at Amphoe Nhongyai, 760,900E (UTMx) and 1,452,648N (UTMy). Total area was 3.36 ha for one crop plot (120m×290m). From field survey in Nhongyai District, total area of one owner was 80 ha, which was located in many areas. One plot size was 3.2 ha and some plots were 0.8 ha depending on natural water resource. This area has been cultivated for 20 years.

On 23/01/2009, sampling site location is in Amphoe Banbueng far from Nhongyai for 30 km. UTM coordinate of sampling site was recorded by GPS at 737,094E (UTMx) and 1,469,383N (UTMy). Total area is 4.48 ha for one crop plot (150m×300m). In Ban Bueng district, total area of one owner was 32 ha, which was divided into 9.6 ha or 1.6 ha per plot. This land has been cultivated for 50 years. Three sugarcane sites were cultivated by seeding (add pig manure), seeding (no pig manure), and ratoon.

b.1) Banbueng 2008

On 29/02/08 experiment, sugarcane type K 95-84 and K88-92 was cultivated in March 2007 and harvested in February 2008. Therefore, cultivated duration is 11 months. Row width is 150 cm. Information from the interview indicates that production is decreased when harvested in the next ratoon by around 30%. Burning is usually done when the last ratoon is harvested. From the interview, product is usually around 62.5 ton/ha and sweetness is 10.5 CCS.

b.2) Nhongyai 2009

On 22/01/2009 at Nhongyai, sugarcane type K95-84 was harvested for 100 days in December to March, which was done by labor. Labor cost of harvesting freshly (not burn) was 170 baht/ton (30 ton/day by 30 labors) and burn before harvest was 130 baht/ton (50 ton/day by 30 labors). Although, labor cost is cheaper for burning before harvesting, farmers prefer fresh harvesting because of higher price earning from selling to the sugarmill. But labor is scarce, so harvested method is managed by labor decision. Most laborers are form northeastern region of Thailand. Usually, burning is conducted at 19.00-22.00 before harvesting in the morning. Reason of burning is for easy harvesting. At this time, fresh harvesting was 9.6 ha and burned harvesting was 16 ha. Sugarcane residues have not been used. Leaves were ploughed back into the soil. Product of seeding sugarcane is 87.5-93.75 ton/ha and ratoon sugarcane is 1.28-1.60 ton /ha. Sweetness of sugarcane is 10-12 CCS. Farmers prepare land in January to mid of February, which takes 10-15 days. Planting is done at the same period and takes 10-20 days by 20 laborers. Distance between rows is 130 cm and between stem in the same row is 15 cm. Total rows in 0.16 ha is 27 rows. Biological fertilizer (chicken manure) was applied when planting and chemical fertilizer (46-0-0) was applied after 2 months. The amount of chemical fertilizer to the land was 6.25 kg/ha and cost of the fertilizer was 30,000 baht/ton. Herbicide and pesticide were not applied in this land.

b.3) Banbueng 2009

On 23/01/2009 at Banbueng, sugarcane type of this batch was K88-92, and previous types were Uthong 7, K9584, Uthong1, and Khonkaen 3. Duration of one batch was 12 months. The land was prepared from March to April. Distance between rows and stems were the same as Nhongyai district. Chicken manure and chemical fertilizer (16-20-0) were used when seeding, then after 4 months chemical fertilizer (15-15-15) was applied. Herbicide was used during seeding. Harvesting was done from mid December to March. The product was sold to Sahakarn Sugarmill. Production of seeding sugarcane was 75 ton/ha and ratoon sugarcane was 50 ton/ha. Sweetness was 10 CCS. Fresh cane harvesting labor cost was 170 baht/ton and burned cane labor cost was 130 baht/ton. Less than 1% of top was used for cow feeding. Burning is usually done before harvesting at night; it takes half an hour. After harvesting by burning for 12 hours, products were delivered to sugar mill. Reason of burning was for easy harvesting. Ignition was done at many points to remove leaves. Combustion was in a short time to cause less damage to the cane. However, during that time sugar mill was closed so farmers did not burn sugarcane.

Type, duration, and land preparation were the same between Nhongyai and Banbueng, but a difference in fertilizer and pesticide/herbicide applied. Therefore, production quantity and sweetness were a little different.

Biomass load is g/m^2 for sugarcane leaves in Chonburi. From the interview, product is usually around 62.5 ton/ha and sweetness is 10.5 CCS. However, the average dry product in the experiment is 35.63±14.38 ton/ha (3,560±770 g/m^2). Moisture content of cane is 75%±2% and other part of sugarcane is 67%±2% in top. Leaves are totally dry with 0% moisture. Average BL of sugarcane leaves is 928±262 g/m^2 and top is 524±153 g/m^2. Height of sugarcane from top to the ground is 296±59 cm. RPR of sugarcane leaves is 0.24±0.02 for dry product.

3.3.5 Results of Biomass Load Assessment

Average results of BL from field experiments in rice, corn, and sugarcane field are presented in Table 3.4.

Table 3.4 Summary of biomass load results (g/m^2)

Crop type	Biomass type	BL (g_{dm}/m^2) this study	BL (g_{dm}/m^2) other studies
Rice	Straw	421±131	240[a], 270[b], 605[c], 550[d]
Rice	Stubble	261±120	-
Irrigated Rice	Straw	360±56	-
Irrigated Rice	Stubble	220 ±53	-
Rain-fed Rice	Straw	507±146	-
Rain-fed Rice	Stubble	321 ±162	-
Corn	Corn residues	610±153	890[c], 1,000[d]
Sugarcane	Leaves	1,007±295	650[d]
Sugarcane	Top	523±137	-

Note: [a] Garivait, 2006 (Thailand); [b]OEPP, 1990 (Thailand); [c]Jenkins et al., 1996 (USA); [d]IPCC, 2006

From Table 3.4, the BL result of rice straw in this study is in the same range as other studies minimum value is similar to the studies in Thailand and maximum value is similar to the studies in USA and IPCC (2006). However, the BL result of corn residues in this study is lower than other studies in USA and IPCC (2006). The BL result of sugarcane is higher than IPCC (2006), which does not indicate type of sugarcane residues (leaves, top, or leaves and top).

Parameter that have influence on the BL of rice consists of harvesting activity, i.e. height of stubble has effect on amount of straw, even different crop plots in the same area; double height of stubble causes decreasing double amount of straw in case of Nakhonsawan Thatako experiment on 29/12/2009; period of cultivation, i.e. period of irrigated rice is 80-140 days - produces lower amount of straw than rain-fed rice that is cultivated in 180 days. Biomass of rice straw is classified into major and second rice. Major Rice means rice that cultivates from May 1 to October 31. Second rice means rice that is cultivated in dry season or off rainy season during November 1 to April 30 in the next year. BL results of major and second rice are presented in Table 3.5.

Table 3.5 Biomass load of rice straw in irrigated and rain-fed paddy area

Biomass load (g/m^2)	Irrigated	Rain-fed
Major	400±165	507±305
Second	307±108	-

From Table 3.5, there is no significant difference between BL of major and second rice, but significant difference was found between amount of BL between irrigated and rain-fed rice. Therefore, emission factor was estimated in irrigated and rain-fed area. However, rain-fed rice is usually cultivated once a year because of water resource being available, so rain-fed second rice is not considered. High variation in BL rain-fed rice was found because of difference in row and between rows rice straw.

From the BL results of stubble in the irrigated and rain-fed rice field, height and dry weight of stubble were measured and graph was plotted to observe their relation. The results of irrigated rice are presented in Figure 3.6 and the results of rain-fed rice are presented in Figure 3.7.

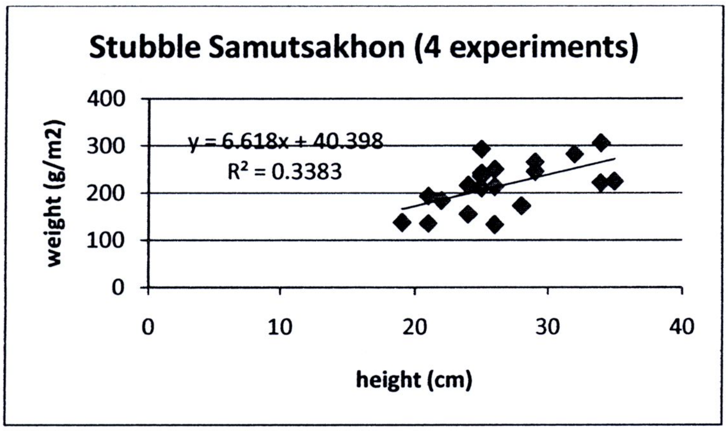


Figure 3.6 Relationship between height and weight of stubble in irrigated rice.

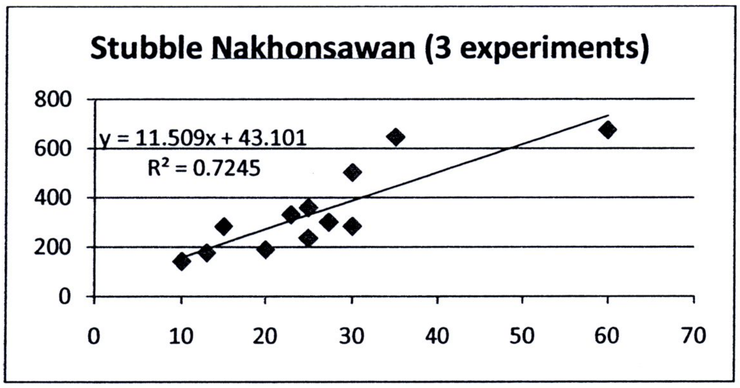


Figure 3.7 Relationship between height and weight of stubble in rain-fed rice.

Relationship between weight and height of stubble is linear. From the relationship, weight of stubble can be predicted when the height is known. Average height of stubble in irrigated rice is 20-35 cm, and rain-fed rice is usually 10-30 cm. In some area, rain-fed rice stubble is high because rice bends down naturally, so harvesting is done at higher part for 60 cm stubble. Size of the stubble in rain-fed area is larger than irrigated area by observing at the same height, weight of stubble in rain-fed rice is larger. The result is consistent with BL that BL result in rain-fed rice is larger than in irrigated rice.

3.3.6 Results of Fraction Burn

Fraction burn of agricultural residues in rice, corn, and sugarcane fields was obtained from field survey. In the field that agricultural residues were burned, their residues were not utilized or moved out of the field so total of agricultural residues were burned in the field. Therefore, fraction burn of agricultural residues in rice, corn, and sugarcane fields was 100%.

3.3.7 Results of Combustion Efficiency

Combustion efficiency was calculated from measuring biomass before and after the open burning experiment in the field. Results are presented in Table 3.6 as average value from the field experiments. The results are separated between wet and dry season because moisture content in biomass and soil has influence on combustion of biomass.

Table 3.6 Results of Combustion Efficiency

Crop type	Biomass type	CE wet condition (%)	CE dry condition (%)
Irrigated rice	Rice straw	100	100
Irrigated rice	Rice stubble	41	63
Irrigated rice	Straw and stubble	68	80
Rain-fed rice	Rice straw	100	100
Rain-fed rice	Rice stubble	77	7
Rain-fed rice	Straw and stubble	49	94
Rice	Rice straw	100	100
Rice	Rice stubble	59	35
Rice	Straw and stubble	59	87
Corn	Corn residues	45	88

Note: Rice means average value between irrigated and rainfed rice

From Table 3.6, low CE was found in wet season in both rice and corn residues open burning because of high moisture content in biomass and soil. The unburned part of rice was stubble and corn was mostly stem.

3.3.8 Results of Residue to Product Ratio

The RPR information was available from the BL results from field experiments and product from field survey. Results of the RPR are presented in Table 3.7.

Table 3.7 RPR results

Biomass	BL (g/m^2)	Product (g/m^2)	RPR	Other studies
Rice straw	421±131	751±320	0.72±0.40	0.75[a], 0.49[b], 1.4-2.9[c] 1.4[d]
Rice stubble	261±120	751±320	0.43±0.25	-
Irrigated rice straw	360±56	607±350	0.85±0.48	-
Rain-fed rice straw	507±146	942±110	0.55±0.11	-
Corn residues	610±153	619±63	0.97±0.20	0.89[a], 2.0-2.3[c] and 1.0[d]
Sugarcane leaves	1,007±233	6,308±942(wet)	0.16±0.03	
Sugarcane leaves and tops	1,704±527	6,308±942(wet)	0.24±0.04	0.23[a], 0.20[b]

Note: 1) [a]PCD, 2007, [b]DEDE, 2009, [c]Barnard et al., 1985, [d]IPCC, 1996

2) Sugarcane production is wet weight

From Table 3.7, the RPR result of rice straw in this study is 0.72±0.40, which is classified in irrigated rice straw 0.85±0.48 and rain-fed rice straw 0.55±0.11. The RPR results of rice straw are in the same magnitude as other studies in Thailand (PCD, 2007 and DEDE, 2009), but lower than other studies in South Asia (India, Pakisthan, and Bangladesh) where the rice is cut at about 2 inches above ground (Barnard et al., 1985) and also lower than IPCC (1996). The corn residues in this study include leaves, stem, and envelope. The RPR corn result is the same as leaves and stem studied in Thailand (PCD, 2007 and DEDE, 2009).

RPR specific to sugarcane leaves is not available, so the results compare with other studies by results of sugarcane top and leaves RPR result, and it was found that this result is in the same range as other studies in Thailand (PCD, 2007 and DEDE, 2009).

3.4 Proximate and Ultimate Analysis

Samples that were collected from field experiment consisted of biomass, ash, and aerosol. These samples were analyzed by proximate and ultimate analysis to consider their properties as follows:

3.4.1 Sample Preparation

a) Biomass Samples

Biomass samples (rice straw, rice stubble, corn residues, sugarcane leaves, and sugarcane top) were dried by being placed in the oven at 70°C to remain carbon component. Dried biomass was cut by cutting mill (Retsch, Model SM 2000, Germany) and grinded by Planetary Ball Mill (Retsch, Model PM 100, Germany). Then select size of biomass at 106 μm by sieving to prepare sample for proximate and ultimate analysis. After that, the samples were kept in desiccators.

b) Ash Samples

Ash samples were dried at 70°C oven. Then sieved at 106 μm and stored in desiccators.

3.4.2 Proximate Analysis

Proximate analysis was conducted by following standard test method (international standard: ASTM D3172). The proximate analysis covered the determination of moisture, volatile matter, and ash and the calculation of fixed carbon on biomass and aerosol samples. Proximate analysis was done by Thermogravimetric Analyzer (TGA Perkin Elmer, model Pyris 1, USA). Nitrogen was used for carrying gas by applying 50 ml/min. Amount of sample input into the TGA was approximate 5 mg. Analyzed method was conducted by Step 1 heat from room temperature to 110°C by increasing 10°C/min and hold for 10 min at 110°C, and Step 2 heat from 110°C to 900°C by increasing 10°C/min and hold for 10 min at 900°C. An example of the results is presented in Figure 3.8.

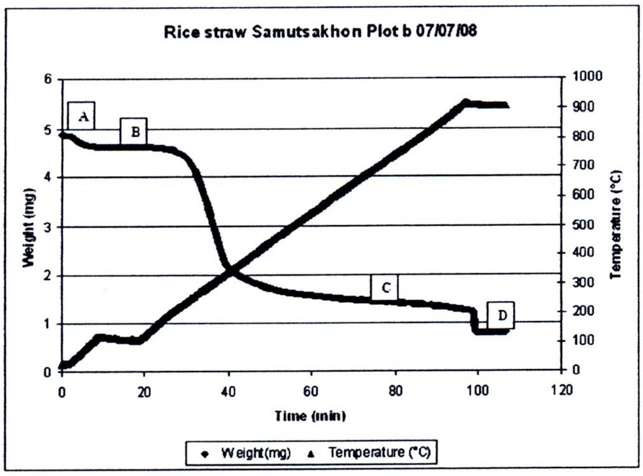


Figure 3.8 Proximate analysis.

From Figure 3.8, moisture content, VOC, ash, and fixed carbon are known by moisture content: the weight that has been lost at 110°C, which calculates by Eq. 3.5; VOC is lost during temperature, increased to 900°C (Eq. 3.6); ash is the non-combustible residue left after the biomass is burnt, it represents the bulk mineral matter after carbon, oxygen, sulfur and water (including from clays) has been driven off during combustion; and fixed carbon is obtained by Eq. 3.7 calculation.

Moisture in analysis sample, % = $\left[\left(\frac{A-B}{A}\right)\times 100\right]$ Equation 3.4

where: A = grams of sample used and B = grams of sample after heating at 110°C. The moisture percentage is based on air dry biomass or A weight. However, the moisture content is the amount of water after air dry by being naturally dried and at temperature 70°C for 24 hours.

VOC in analysis sample, % = $\left[\left(\frac{B-C}{B}\right)\times 100\right]$ Equation 3.5

where C is grams of sample after heating at 900°C. Volatile matter refers to the components of biomass, except for moisture, which is liberated at high temperature in the absence of air. This is usually a mixture of short and long chain hydrocarbons, aromatic hydrocarbons, and some sulfur.

Fixed carbon, % = 100- (moisture, % + ash, % + volatile matter, %)   Equation 3.6

The fixed carbon content is the carbon found in the material, which is left after volatile materials are driven off. The result of fixed C in proximate analysis differs from the ultimate carbon content because some carbon is lost in hydrocarbons with the volatiles. Results of proximate analysis are presented in Table 3.8.

Table 3.8 Proximate analysis results of biomass (dry basis)

Crop type	Experimental site	Sample type	%fixed carbon	%volatile matter	%ash
Rice	Samutsakhon, Ratchaburi	Straw	10.96±0.97	72.38±2.68	16.66±2.54
Rice	Samutsakhon	Stubble	11.30±0.82	72.62±0.76	16.08±0.06
Sugarcane	Kanchanaburi, Chonburi	Leaves	10.15±0.50	70.00±3.11	19.86±3.61
		Average	10.90±0.95	72.11±2.71	16.99±2.77

From Table 3.8, the proximate analysis results of biomass (rice straw, rice stubble, and sugarcane leaf) are in the same range with 10.90±0.95% fixed carbon, 72.11±2.71% volatile matter and 16.99±2.77% ash. Sample of ash from rice residues open burning was also analyzed. The result is presented in Table 3.9.

Table 3.9 Proximate analysis results of ash (dry basis)

Crop type	Experimental site	Sample type	%fixed carbon	%volatile matter	%ash
Rice	Samutsakhon	Ash	11.85±2.88	17.41±0.00	70.74±2.88

From Table 3.9, Low volatile matter and high ash were found in ash sample, but fixed carbon was consistent with biomass samples.

3.4.3 Ultimate Analysis

Ultimate analysis was conducted by thermal method with Elemental Analyzer (Thermo Fisher Scientific, Model Flash EA 1112 NC SERIES, UK). Detail of proximate and ultimate analysis was described. The ultimate analysis was conducted to determine carbon (C), hydrogen (H), and nitrogen (N) in the sample. Principle of this elemental analyzer is based on dynamic flash combustion. The content of N, C, and H was detected by area of graph that presented at around 57, 85, and 370 s, respectively. The result from the analyzer was calculated by

$$K = \left(\frac{Area_{STD} - Area_{Blank}}{\%STD \times W_{STD}} \right) \times 100 \qquad \text{Equation 3.7}$$

where, $Area_{STD}$ and $Area_{Blank}$ are area under the curve of standard chemical and blank, respectively. %STD is percentage of C, H, or N in the standard chemical.

$$\%C, H, orN = \left(\frac{Area_{UNK} - Area_{Blank}}{K \times W_{Unk}} \right) \times 100 \qquad \text{Equation 3.8}$$

where, W_{Unk} is weight of unknown sample.

a) Ultimate Analysis for Biomass

The biomass samples include rice straw, rice stubble, corn residues, sugarcane leaves, and ash sample of rice, corn, and sugarcane. The chemical standard is BBOT, which consists of 6.51%N, 72.53% C, and 6.09% H. Each batch of the ultimate analysis, the biomass sample 4 mg was wrapped in the Universal Tin container and input in the elemental analyzer. Samples that placed in the elemental analyzer consist of empty universal tin (blank), approximate 4 mg BBOT contain in universal tin (standard), and approximate 4 mg biomass sample contain in universal tin (unknown). The ultimate analysis was done sequentially as follows: Input empty Universal Tin container into the elemental analyzer as a blank for three replicates. Then put chemical standard contained in Universal Tin container for three replicates. After that, samples were put into Universal Tin container and placed into the analyzer for three replicates. When samples analysis was finished, chemical standard contained in Universal Tin container was analyzed for three replicates. Finally, empty Universal Tin container was analyzed for three replicates. Carrier gas that was used in the experiment was helium gas (He). Temperature was increased to 950°C. Results of ultimate analysis to characterize chemical component of agricultural residues are presented in Table 3.10.

Table 3.10 Ultimate analysis results of biomass

Biomass	This study			Others		
	%N	%C	%H	%N	%C	%H
Rice straw	0.79±0.30	36.98±2.62	5.31±0.39	0.6[a], 0.87[d]	44.4[a], 38.24[d]	5.0[a], 5.2[d]
Corn residues	1.45±0.23	39.74±0.99	5.92±0.47	1.3[a], 1.62[c]	44.2[a], 41.09[c], 34.81[e]	5.8[a], 6.85[c], 3.56[e]
Sugarcane leaves	0.71±0.09	39.11±0.73	5.63±0.11	0.8[a], 0.19[b], 0.16[d]	44.9[a], 39.8[b], 48.64[d]	5.9[a], 5.5[b], 5.87[d]

Note: [a]Garivait and Chaiyo, 2006 (Thailand); [b]Jorapur and Rajvanshi, 1997 (India); [c]Li et al., 2007 (China); [d]Jenkins et al., 1998 (USA: sugarcane bagasse); and Zhang et al., 2000 (China)

From Table 3.10, ultimate results are consistent among rice straw, corn residues, and sugarcane leaves. Moreover, the results are in the same range with other studies in Thailand (Garivait and Chaiyo, 2006), India (Jorapur and Rajvanshi, 1997), China (Li et al., 2007), and USA (Jenkins et al., 1998). Therefore, characteristics of agricultural residues are not different from one country to another country.

b) Ultimate Analysis for Ash

The ash samples were obtained from open burning experiment of rice, corn, and sugarcane residues. The ultimate analysis method for ash samples were the same as biomass samples. Therefore, ash samples were conducted in the same batch as biomass samples. Results of ultimate analysis to characterize chemical component of ash are presented in Table 3.11.

Table 3.11 Ultimate analysis results of ash

Sample	%N	%C	%H
Ash straw	0.41±0.08	12.47±1.59	0.83±0.19
Ash corn	0.33±0.11	11.12±1.93	0.97±0.09
Ash sugar	0.40±0.02	9.53±2.49	0.70±0.29

From Table 3.11, ultimate analysis results of ash from rice, corn, and sugarcane open burning are in the same range.

3.5 Weight Balance

The weight balance refers to balance of biomass weight before and after open burning in the field in order to estimate amount of mass released into the atmosphere. Calculation of weight balance is presented in Equation 3.9.

$$B_{released\ to\ atmosphere} = B_{burned} - B_{ash} \qquad \text{Equation 3.9}$$

where $B_{released\ to\ atmosphere}$ is amount of burned biomass released into the atmosphere after burning, B_{burned} is amount of burned biomass ($B_{biomass}-B_{unburn}$), and B_{ash} is amount of ash that remains in the field after burning. Each parameter was obtained from field experiments on dry weight basis. Results of the weight balance are presented in Table 3.12.

Table 3.12 Weight balance of agricultural residues open burning

Crop	Biomass	B_{burned} biomass (g/m^2)	B_{ash} (g/m^2)	$B_{released\ to\ atm.}$ (g/m^2) (%)
Irrigated Rice	Straw and stubble	505±143	70±48	435±111 (87±7)
Rainfed Rice	Straw and stubble	668±118	27±9	640±109 (96±1)
Corn	Leaves, stem, and envelope	448	9±1	440 (98)
Sugarcane*	Leaves	1,050±255	65±18	986±240 (94±1)

Note: * Sugarcane data from chamber experiments

From the open burning of agricultural residues in field experiments, after burning, most mass of biomass released into the air for 87%±7% of irrigated rice residues, 96%±1% of rainfed rice residues, 98% of corn residues, and 94%±1% of sugarcane leaves.

3.6 Conclusions

1) Biomass load of major economic crops in Thailand consists of rice straw 421±235 g/m^2, corn residues 610±153 g/m^2, and sugarcane leaves 1,007±233 g/m^2. The results of this study cover results of other studies in Thailand (Garivait, 2006 and OEPP, 1990) and in USA (Jenkins et al., 1996 and IPCC, 2006)

2) This study has determined the BL in paddy field by classification into irrigated and rain-fed area: 360±140 g/m^2 in irrigated rice field and 507±305 g/m^2 in rain-fed rice field

3) Parameters that have influence on BL of rice are: period of cultivation, topography, cultivation practice, and crisis situation (flood or drought)

4) Major influence on the combustion efficiency of both rice and corn residues open burning in the field is wet and dry season

5) Most burned biomass released into the air for 87%±7% of irrigated rice residues, 96%±1% of rainfed rice residues, 98% of corn residues, and 94%±1% of sugarcane leaves