Black Carbon Emission from Paddy Field Open Burning in Thailand

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Abstract—Black carbon (BC) contributes directly and indirectly to the Earth’s radiative balance change, and consequently, has impact on global warming as the second largest contributor after carbon dioxide. One of the major sources of aerosol emission from biomass burning is open burning of agricultural residues. In many countries, open burning in the paddy field is a common way to eliminate rice residues after harvesting, including Thailand, one of the world’s largest rice exporters. During rice harvesting seasons, open burning of rice residues in the field releases a large amount of aerosols. However, limited studies have been conducted to quantify BC emissions from open burning of rice residues in Thailand.

This study aims to assess amount of BC emission from open burning of rice residues in Thailand. Open burning experiments were conducted both in the field and in the chamber to simulate open burning in order to determine emission factor of BC emissions, including PM$_{2.5}$, CO, and CO$_2$ through continuous real time equipment measurement. Field experiments were carried out in paddy field in central region of Thailand to obtain biomass load (g/m$^2$), residue to product ratio (RPR), fraction of biomass subject to burning in the field after utilization (%), and combustion efficiency (%), respectively. Rice residues and ash were also collected to determine moisture content in the laboratory to obtain biomass load in dry matter.

Field experiments were conducted in Samutsakhon province to represent for irrigated paddy field; and in Nakhonsawan province to represent for rain-fed paddy field. Biomass load of rice straw in irrigated and rain-fed paddy field are 360±140 and 507±305 g/m$^2$, respectively. Result of RPR in irrigated area is 0.85±0.48 and rain-fed area is 0.55±0.11.

Emission factor results of BC from open burning experiment in the chamber are 0.79±0.36 gBC/kg$_{\text{dm}}$ from rain-fed rice residues burning and 0.72±0.03 gBC/kg$_{\text{dm}}$ from irrigated rice residues burning.

Burned area of irrigated and rain-fed paddy field was obtained from agricultural statistical data and questionnaire results. Total burned area of irrigated paddy field is 2.69 million ha, and rain-fed paddy field is 1.21 million ha. Black carbon emission from irrigated paddy field is 6,973±113 ton/y and from rain-fed paddy field is 4,846±1,329 ton/y. Total amount of BC released from in-field open burning in Thailand is 11,819 ton annually.

Keywords-component; black carbon; global warming; rice residues; open burning

I. INTRODUCTION

Black carbon (BC) is generated from burning of carbon contained fuel, which one of major sources is biomass burning. Due to structure of BC consist of graphitic microcrystalline, so it is strongly absorb solar radiation and its effect may extend over regional to global scale [1]-[4].

Emission factor (EF) of BC from agricultural burning has been estimated in global agricultural residue by best guess from compiling information, 0.69±0.13 g/kg [5]. The EF of BC from rice straw burning has studied by simulating open fires of rice straw in chamber to measure EC and obtain 0.17±0.04 g/kg from rice straw sample in USA [6].

In many countries, open burning in the paddy field is a common way to eliminate rice residues after harvesting, including Thailand, one of the world’s largest rice exporters. Thailand is an agricultural based economy. In 2008, cultivated area of rice was 11.2 million ha, which was harvested for 10.7 million ha [7]. In order to increase production to assure exportation, farmers cultivated 2-3 crop cycles per year in irrigated area. To prepare the land for the next cultivation, open burning is selected to remove rice residues in the field because it is the most convenient and the lowest cost method. That is one reason of biomass open burning in Thailand. During rice harvesting seasons, open burning of rice residues in the field releases a large amount of BC. However, limited studies have been conducted to quantify BC emissions from open burning of rice residues in Thailand [8]. Purpose of this study is to investigate the BC emitted from rice field open burning in Thailand.

II. METHODOLOGY

Methodology to estimate emission from paddy field open burning is described as follows.

A. Estimation of Emission

Estimation of emissions from rice residue open burning is assessed by

$$E = M \times EF$$  (1)

$$E$$: Emission of black carbon

$$M$$: Burned area of rice residue

$$EF$$: Emission factor of black carbon from burning rice residue
where $E_i$ is the emission of pollutant $i$, $M$ is the amount of biomass burned (kg) and $EF_i$ is the emission factor of pollutant $i$ (EF$_i$) (g pollutant/kg dry mass). $M$ is burned rice residues (kg$_{dm}$) obtained by

$$M = A \times BL \times FB \times CE$$  \hspace{1cm} (2)

$A$ is burned area ($m^2$), $BL$ represents biomass load (kg$_{dm}$/m$^2$), $FB$ is fraction of biomass subject to burning after utilization (%), and $CE$ is combustion efficiency (%). $M$ was obtained from the field experiment and $EF$ was available from open burning experiment in the field and the chamber. This calculation is the same as IPCC, 2006 [9].

B. Estimation of burned area

Estimation of burned area was conducted through questionnaire. Paddy field area is classified as irrigated and rain-fed paddy field because of difference in biomass load results that has influence on BC emission. To obtain the burned area, questionnaire was distributed by field survey in each region of Thailand. Group of farmers was interviewed. The results were in percentage of burning and analyzed to obtain burned area in both rain-fed and irrigated area of the country.

C. Biomass quantification

In this study, biomass is focused on rice straw. Field experiments were conducted to determine biomass load, fraction burn, combustion efficiency, and residue to product ratio. Experiments were carried out in Samutsakhon province to represent for irrigated area, and in Nakhonsawan province to represent for rain-fed area, during year 2007 to 2010. All experiment sites are located in central region of Thailand, where plenty of rice is cultivated and accessible for field experiments. Straw sample was collected in the field for 1×2 m$^2$ area to cover row and between rows. Wet weight of straw samples were recorded at the field and brought back to analyze for moisture content at the laboratory at 70°C in the oven. Biomass size was reduced to 106 µm to analyze for elemental components through ultimate analysis using elemental analyzer (FLASH 1112 SERIES) at 900°C.

D. Emission factor

1) Open burning experiments in the field

Open burning experiments were conducted in Samutsakhon and Nakhonsawan because burning rice residues is a common practice in these areas. Locations of the studied sites on Thailand map are presented in Figure 1.

Samutsakhon province is located in central region of Thailand, 30 km from Bangkok. Nakhonsawan province is in upper part of central region of the country. In both provinces, rice was cultivated by broadcast and harvested by machine. The harvested machine spread the straw after grain separation in rows. Row size was 1 m width. Harvesting in Nakhonsawan is done once a year, and in Samutsakhon is 2-3 times per year.

Meteorological condition was measured at the studied site through the experiment period by weather station (Lacrosse Technology, model ws1600, USA). Parameters of monitored meteorological condition consisted of wind speed, wind direction, temperature, pressure, and humidity. Measurement of these parameters was conducted in order to see influence of meteorological condition on BC emission.

The prescribed burn experiments were conducted at the field by burning in 1×1 m$^2$ and traditional burn experiments (n=11) were also carried out by burning for the whole plot to represent for traditional way (n=7, BC measurement in 3 experiments). Burning rice residue was done in rows (Figure 2) because straw was placing in rows by harvested machine. Emissions were measured and sampling at ground level 1.5 m height near the fire, which tried to keep position in the plume by moving the equipments along the plume direction. Measurement of pollutants was conducted real time with 1 s frequency through air quality monitoring equipments consist of Dusttrak (PM$_{2.5}$), Micro Aethalometer (BC), and Quest Suite AQ Pro 5000 (CO and CO$_2$). The air quality monitoring was conducted before the experiment to obtain ambient air concentration and during the open burning to measure emission from open burning of rice residues, respectively. Time of burning was recorded to obtain burned rate, especially in 1 m$^2$ burning that amount of biomass was known. After combustion, ash and unburn were collected to analyze for moisture content to obtain dry mass for determining CE and also analyze for elemental components.
2) Open burning experiments in the chamber

The chamber was designed to simulate open burning in the field, which was observed in the field experiments that meteorological condition was calm wind. It is located in KMUTT Ratchaburi campus. Figure of the chamber is presented in Figure 3. Three sides of combustion zone are closed by heat durable steel sheet and one side is opened for let air in or out without any control. Rice straw was prepared in the same amount as 1 m$^2$ from field experiment results. The straw was burned on the tray to be able to measure exact weight before and after burning. During combustion, time was recorded and emission was measured by the same equipments and the same method as field experiments. The emission measurement equipments were installed in front of opened side chamber at ground level for 1 m height. Meteorological condition and ambient air quality were also measured.

3) Emission factor calculation

Emission factor (EF) from open burning of rice residues in the field and in the chamber was obtained by following equation.

$$EF = \frac{C_i}{BR}$$

where, $C_i$ is emission concentration of pollutant $i$ (mg/m$^3$) and BR is burned rate (g/s). The units of BC, CO, and CO$_2$ concentration were changed from µg/m$^3$ and ppm to mg/m$^3$. Then ambient concentration was removed to obtain emission concentration. After that, the results were divided by burned rate of each experiment.

III. Results and Discussion

A. Burned area of open burning in rice field

Burned area of irrigated and rain-fed paddy field was obtained from Thai agricultural statistical data [10] and questionnaire results. Total burned area of irrigated paddy field is 2.69 million ha, and rain-fed paddy field is 1.21 million ha. These results account for 70% of irrigated rice field area and 18% of rain-fed rice field area of Thailand. Most rice field open burning was found in irrigated area because farmer cultivates 2-3 times a year so burning is usually found to eliminate residues for land preparation for the next cultivation.

B. Biomass

Field experiment results of biomass quantification are presented in Table 1. Harvesting at the studied sites was done by the same way that using machine cut at 15-34 cm above ground. Short/long cultivated period has a major influence on rice straw amount. Irrigated rice cultivates for 80-120 days, which is shorter period than rain-fed rice cultivates for 180 days. Therefore, larger amount of biomass was found in rain-fed area because of longer cultivation period. Result of RPR is also presented in Table 1. The result is higher than estimated by energy sector literature 0.49 [11].

<table>
<thead>
<tr>
<th>Water resource</th>
<th>Irrigation</th>
<th>Rain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass load (gdm$^2$/m$^2$)</td>
<td>360±140</td>
<td>507±305</td>
</tr>
<tr>
<td>RPR</td>
<td>0.85±0.48</td>
<td>0.55±0.11</td>
</tr>
</tbody>
</table>

Rice straw was totally burned in the field so combustion efficiency (CE) was 100%. After burning, unburn part was stubble and ash was left in the field. Usually, the rice field where burning is presented, a little or no rice straw is utilized for <1% so straw utilization in burned rice field can be neglected. Therefore, fraction burn was 100%.

C. Emissions

Emissions of BC, PM$_{2.5}$, CO$_2$, and CO from open burning of rice residues are measured by real time monitored equipment. In this research, estimation of BC from open burning in the rice field is the target. Other pollutants (PM$_{2.5}$, CO$_2$, and CO) are also considered to investigate combustion characteristics. The emissions were measured in form of concentration (mg/m$^3$ PM$_{2.5}$, ppm CO and CO$_2$, ng/m$^3$ BC) that contained many peaks in each experiment. Example of
result from real time emissions measurements (mg/m$^3$) for one peak during experiment from open burning of rice residue conducted at the field in Nakhon Sawan is presented in Figure 4-5.

![Figure 4](image)

**Figure 4.** Example of results of real time BC, PM$_{2.5}$, CO and CO$_2$ for one peak from rice residue open burning in the field.

![Figure 5](image)

**Figure 5.** Example of results of real time BC for one peak from rice residue open burning in the field.

From Figure 4, the graph presents concentrations of BC, PM$_{2.5}$, CO and CO$_2$ at a moment, because different equipments received the same air volume at the same time due to installation of inlet close together. It can represent trend of each pollutant during combustion. At the initial phase, all pollutants’ concentration rise up and reach maximum after one minute burning. After that, all pollutants’ concentration is decreased and started a new loop again. Many loops can occurred at the same time during traditional burning. Sometimes, the wind changed its direction so the equipment detected ambient air. The ambient concentration was removed and did not take in to account for EF.

The concentration of BC is quite small when compare with PM$_{2.5}$, CO and CO$_2$ so separate BC concentration is presented in Figure 5. Trend of BC concentration is influenced by meteorological condition in the field so the peak is quite unstable all the time. Peak of BC cannot separate each phase of burning. In order to reduce influence of surrounding effect, rice residue was burned in a chamber that can simulate open burning in the field. Example of result of emission measurement in the chamber is presented in Figure 6 and 7.

![Figure 6](image)

**Figure 6.** Example of results of real time BC, PM$_{2.5}$, CO and CO$_2$ from rain-fed rice residue open burning in the chamber.

![Figure 7](image)

**Figure 7.** Example of results of real time BC from rain-fed rice residue open burning in the chamber.

From Figure 6, results of simulate open burning in the chamber present the same trend as open burning in the field, but more clearly peak. Flaming phase is presented at the initial phase of combustion in 1 min. After that, smoldering phase is presented until distinguish. BC is also released in the flaming phase, which can be seen in Figure 7. Emission factor from open burning of rice residues results are presented in Table 2.

**TABLE II. Emission factor of BC from open burning of rice residues**

<table>
<thead>
<tr>
<th>Emission factor</th>
<th>BC (g/kg$_{dry}$)</th>
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<tbody>
<tr>
<td>Field</td>
<td>0.06±0.02</td>
</tr>
<tr>
<td>Chamber (Rain-fed)</td>
<td>0.79±0.36</td>
</tr>
<tr>
<td>Chamber (Irrigation)</td>
<td>0.72±0.03</td>
</tr>
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</table>

From Table 2, the field emission factor obtained from experiments of traditional open burning in the field in Nakhonsawan province. Emission factor of BC from open burning of rice residues in the field is 0.06±0.02 g/kg$_{dry}$, which is lower than in the chamber for magnitude of 10 because influence of surroundings, especially meteorological condition. The environmental influence is decreased when simulate open burning of rice residues in the chamber and carbon components of rice straw from ultimate analysis are
the same in both irrigated (38±4.2%) and rain-fed area (34±2.2%) are the same so emission factors of BC from rain-fed and irrigated rice straw are the same, 0.79±0.36 g/kg and 0.72±0.03 g/kg for rain-fed and irrigated rice straw open burning, respectively. The results of this study are consistent with other studies i.e. agricultural residues burning released 0.69±0.13 g/kg [4], 0.7-2 g/kg fuel carbon [1]. However, the result is higher than 0.17±0.04 g/kg [6] because of different chamber design and measurement method.

These emission factors were used for estimating emission of BC from rice field open burning in Thailand. Total burned area of irrigated paddy field is 2.69 million ha, and rain-fed paddy field is 1.21 million ha. Therefore, BC emission from irrigated paddy field is 6,973±113 ton/y and from rain-fed paddy field is 4,846±1,328 ton/y, respectively. Total amount of BC released from in-field open burning in Thailand is 11,819 ton/y annually. To identify global warming effect, global warming potential (GWP) was applied. There is no research about GWP of BC from rice residue open burning, respectively. The results of this study are consistent with other studies i.e. agricultural residues burning released 0.69±0.13 g/kg [4], 0.7-2 g/kg fuel carbon [1]. However, the result is higher than 0.17±0.04 g/kg [6] because of different chamber design and measurement method.

This study aims to investigate amount of BC emission from open burning of rice residues in Thailand. Field experiments were conducted in irrigated and rain-fed paddy field to quantify rice straw, which is main fuel for combustion. Biomass load in irrigated and rain-fed paddy field are 360±140 and 507±305 g/m², respectively. Result of RPR rice straw in irrigated area is 0.85±0.48 and rain-fed area is 0.55±0.11.

Emission factor results of BC from open burning of RPR rice straw in the chamber are 0.79±0.36 and 0.72±0.03 g/kg, respectively. Total burned area of irrigated paddy field is 2.69 million ha, and rain-fed paddy field is 1.21 million ha. Black carbon emission from irrigated paddy field is 6,973±113 ton/y and from rain-fed paddy field is 4,846±1,328 ton/y, respectively. Total amount of BC released from in-field open burning in Thailand is 11,819 ton/y or equals releasing of 34,278 t CO₂ eq annually, which equals to 189,317 MW productions from natural gas power plant [13].

IV. CONCLUSION

The authors gratefully acknowledged the contribution of Dr. Sirintornthep Towprayoon, Dr. Narsara Thongboonchoo, and Dr. Nitin Tripathi, for their comments and suggestions. The Joint Graduate School of Energy and Environment, KMUTT-Earth Systems Science Research and Development Center, JGSEE Research Group on Aerosol from Biomass Burning to the Atmosphere, and the research and field experiment team, are highly appreciated for their support.

REFERENCES